GROWTH

AND

DEVELOPMENT

OF

CHILDREN

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Preface

HE FIRST EDITION OF *Growth and Development of Children* was so well ceived that a reprint became necessary within the year of its publica- on. With helpful suggestions at hand and new material available, we elcome the opportunity to revise and amend the original volume in is second edition. Among the principal changes are those related to ıysical growth and its recording, statistically and graphically. For these, e work of Harold C. Stuart, Howard V. Meredith and A. Ashley Weech ıs been drawn on for tables and graphs. In a new chapter, two recog- zed authorities in orthodontics and pedodontia, Robert E. Moyers and enneth A. Easlich, Professors of Dentistry, School of Dentistry, the niversity of Michigan, provide material on growth and development the face, jaws and teeth, tooth eruption and malocclusion that is not adily found in pediatric texts and journals. The discussions of the para- sal sinuses and of the feet and their management have been expanded, d numerous minor changes and some corrections have, of course, n made.

s Dr. James L. Wilson pointed out in his foreword to the first edition, original work from which this volume developed began in the Depart- nt of Pediatrics of the University of Michigan in an attempt to provide phic compendium for our undergraduate students and later a manual the Department of Pediatrics and for special classes in the School of blic Health. The next step was to expand it for the use of our graduate dents and pediatric residents, who found it of great help in preparing their American Board examinations. Much of the preliminary cal evaluation was made possible by the generosity of Mead Johnson ompany. In its present form, the manual should prove useful also to ctitioners as a reference for dealing with clinical problems in children

and to workers in related fields, such as those concerned with public h and elementary education.

Wherever possible, tables, graphs, charts or outlines have been in the belief that such devices aid in the brief presentation of some con or trends. However, they tend to have one fault in that they lack d Often an "average" figure does not tell the whole story and shoul qualified by further explanation. We hope that we have reached a h medium in this respect by presenting our material as briefly as is cor ible with a scientific and therefore complete approach.

The material that appears here is an accumulation from many so although we have not hesitated to draw from our personal clinical riences when such information seemed valuable for a point of discu Many departments of the University Hospitals freely offered m that might have value. We wish to thank, in addition to those a specifically mentioned, the scores of physicians, nutritionists, anat and others who have used the book and have made valuable sugg as to ways by which it could be improved.

—E. H. W

—G. H. L.

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Introduction

THE TERMS GROWTH AND DEVELOPMENT are often used interchangeably and it is certainly true that each depends on the other for fruition. In the normal child each parallels the other and any separation would be an artificial one. For convenience, however, we may distinguish between them. We restrict, when possible, the term *growth* to mean an increase in physical size of the whole or any of its parts. Growth, therefore, may be measured in terms of inches or centimeters and pounds or kilograms. It can be measured also in terms of metabolic balance, i.e., retention of calcium and nitrogen by the body. *Development* is used to indicate an increase in skill and complexity of function. The individual develops neuromuscular control, he develops dexterity and he develops character. Maturation and differentiation are frequently used as synonyms for development. Used in this sense, it is evident that development is related to growth but is not the same.

Comparative aspects of growth and development are of special interest. Some of the lower forms of life, particularly certain species of insects, emerge from the egg in a fully mature state, capable of carrying on all of the activities of the adult, including reproduction. Even among some higher forms a considerable degree of maturity is rapidly attained. The newly born guinea pig can shift for himself three days after birth. Man is set apart from other animals by the protracted period of infancy and childhood. Nearly one third of man's life span is spent in preparation for living the latter two thirds. It is as though Nature, cognizant of man's unique cerebral attributes, provides a long training period. He is essentially a learning animal, and biologically speaking he develops so slowly that his mental processes are enabled to use and absorb the cumulative experiences of all that have gone before him.

This inherent urge to grow and develop is very strong in children. It can be blighted by many factors, e.g., malnutrition, various acute and chronic infections, endocrine disturbances and congenital anomalies and malformations. Prenatal influences determine to no small extent the size, viability and general health of the newborn infant. The ability to grow and to develop can be enhanced by proper medical supervision, which includes not only the combating of disease by prophylactic and therapeutic measures but attention also to factors such as nutrition, psychologic status and remedy of congenital deficiencies when possible. Repeated physical examinations are essential to the carrying out of such a program. Krogman has suggested that two types of examination are indicated for the growing child: a "medical health examination," which is an assessment of constitutional vigor and status; a "developmental health examination," which serves as an assessment of individual progress in physical growth and maturation, in mental and emotional expansion and in all other similar aspects. Such a distinction is certainly an artificial one, and although the fundamental idea is sound, we would stress that the examination should take into consideration the whole child.

In subsequent pages we attempt to emphasize the individuality of growth and development. No single arbitrary schedule can be set up for any one child. When this is properly understood and given due consideration, many apparent errors can be avoided in evaluating a child. For instance, we would not expect comparable accretions of height and weight for two children, one of whom was born of Japanese parentage and the other of English parentage, even though both were reared in a similar environment. Likewise, we can state that maturity cannot be measured in terms of years alone. First, there is a difference between the sexes; second, in the same sex there can be considerable variation within normal limits, and, finally, as is well known, various parts and functions within the individual reach maturity at different times. This concept of individuality has gained great impetus in the last decade and has led to the use of outlines and charts on which each child establishes his or her own pattern of development. However, the concept of the usual range or distribution of physical and mental attributes is important, and it is desirable to compare each measurement of the child under observation with this distribution rather than with any single norm. The attempt to secure and interpret a few simple measurements improves clinical judgment and brings to one's attention characteristics which might otherwise be overlooked. We know

that the first indication of disease may be loss of weight or failure to gain weight or to grow in stature. Certain phases of development cannot be easily measured, for example, emotional factors, but this does not decrease their importance in the consideration of the child as a whole. In some of these fields fairly well defined or expected patterns of development have been established and are useful as guiding principles, especially in the instruction of parents.

Every child has the privilege and the right to develop to the limits of his capacity. It is the great responsibility of physicians, parents, educators, public health and social service workers to see that the child is given the best opportunity to carry this privilege and this right through to completion. It is hoped that the information presented in the following pages may serve as a guide to the accomplishment of these ideals. It is only through the continued study of children that optimal levels may eventually be defined and attained.

Although there is great variation, it may be helpful for purposes of discussion to divide the periods of growth. Several different lists have been given by various writers; the following grouping seems satisfactory. Such a division of periods will also acquaint the reader with the terms used hereafter.

Growth Period	Approximate Age
Prenatal	From 0 to 280 days
Ovum	From 0 to 14 days
Embryo	From 14 days to 9 weeks
Fetus	From 9 weeks to birth
Premature infant	From 27 to 37 weeks
Birth	Average 280 days
Neonate	First 4 weeks after birth
Infancy	First year
Early childhood (preschool)	From 1 to 6 years
Later childhood (prepubertal)	From 6 to 10 years
Adolescence	Girls, 8 or 10 to 18 years Boys, 10 or 12 to 20 years
Puberty (av.)	Girls, 13 years Boys, 15 years

Each of the periods has one or more characteristics relative to growth that set it apart from the others aside from the obvious chronologic differences. Prenatal and postnatal growth and development are one continuous

process, but the incident of birth and beginning of extrauterine existence is an important dividing point. The period of the ovum is characterized by increase in complexity with little increase in size. For a part of this time the new organism is self-sufficient, living from its own food stored in the yolk sac. The embryo is parasitic and derives its nutrition from the maternal organism, as does the fetus. It is during the embryonic period that rapid differentiation takes place and all of the systems and organs are established. During fetal life there is further differentiation and early functional activities are apparent. Most pronounced during this time, however, is the rapid increase in body mass. At birth the parasitic existence is terminated, and as a result there are the initiation of respiration, changes in the circulatory system, dependence on an external source of nutrition and on the digestive system for assimilation of the food offered, a greater dependence on the organism's own resources to maintain proper body heat and the excretion of unwanted metabolic substances. It is during the neonatal period that all of these changes of function are being adjusted and finally become fairly well stabilized. Rapid growth and continued maturation proceed during infancy, with especial increase in the functions of the nervous system. Since some of these characteristics hold over into the second year, a few authors include the first two years in infancy. Throughout both early and late childhood, growth is relatively slow but steady. There is increasing co-ordination of functions with the development of skills and intellectual processes. Emotional experiences are undergoing constant fluctuations and perhaps represent the least stable factor in the entire period. The division of childhood into an early and a late period is mainly concerned with the time before and after school is begun.

The period of adolescence has had many definitions. By general use, however, the term is associated with the accelerated growth in height and weight, the appearance of secondary sex characteristics and the decelerating growth curve which follows and which is terminated in the union of the epiphyseal centers and development of the ability to reproduce. More briefly but less exactly stated, adolescence represents the period of "growing up" or the change from childhood to adulthood. There are no sharp lines of demarcation at the start or at the end of this time interval, and for each subject the chronological ages may vary. Puberty refers to the time of appearance of dark, pigmented pubic hair in both sexes and includes the age of menarche in girls. However, in girls the ability to reproduce usually is not established until two or more years after the menarche since

most early menstrual periods are believed to be anovulatory. The beginning of reproductive capacity is even less easily fixed in the male. The appearance of spermatozoa is often considered to coincide with curling of the pubic hair. On the average, puberty is assumed to take place about two years later in boys than in girls.

2

Heredity and Environmental Factors

HEREDITY

THE MATERIALS WITH WHICH embryonic life is begun consist of the cytoplasm and the nucleus of the fertilized egg, received from the two parents. The nucleus contains the genes, which differ much in each individual, and these differences affect all of the characteristics of the organism. The manifestations of the results of differences among the genes are known as heredity. Obviously one cannot hope to cover this broad field in a few paragraphs, and the purpose of this discussion is to point out the more important known factors and to attempt to evaluate them in relation to growth and development.

The nuclear substance of the zygote and of all the somatic cells derived therefrom contains 48 chromosomes, the carriers of the genes. The germ cells (spermatocyte and ovum) contain only half as many chromosomes. The union of two gametes (germ cells) re-establishes in the fertilized ovum the number of chromosomes characteristic of the somatic cells of the species. Twenty-four of the 48 chromosomes are of paternal origin and the other half are of maternal origin. Each series of chromosomes contains a complete assortment of genes and therefore a complete set of developmental potentialities. The paternal and maternal chromosomes can be grouped into 23 homologous pairs containing 23 homologous sets of genes. The single exception is the sex chromosome (see p. 19.) Every hereditary trait is actually under the influence of a pair or several pairs of genes. In general, the two members of a pair have a similar principal function, i.e., regulation of some phase of development. However, they may or may not differ in their qualitative or quantitative potentialities. An individual who carries a pair of genes which tend to produce very

similar or identical results is said to be *homozygous* with regard to genes and the trait. On the other hand, if the members of the pair tend to produce different results, the individual is *heterozygous*. If one of the genes has a more potent influence than the other it is said to be *dominant*, and the relatively weaker gene is called *recessive*. A recessive gene can express its characteristic only when paired with a similar gene or in a homozygous person.

To express the difference in appearance as determined by genes the term *phenotype* is used. This expresses the morphologic or perhaps physiologic characteristic of an individual. *Genotype*, on the other hand, expresses the genetic make-up of the individual, or the combination of genes present.

The formation of germ cells is preceded by a so-called reduction division in which the members of each chromosome pair separate and pass into two different mature germ cells. Each germ cell in man therefore contains 24 chromosomes. There are free intermingling and segregation of what were originally maternal and paternal chromosomes, and the variant germ cells may contain all possible combinations in accord with the laws of chance. With man's 48 chromosomes it has been estimated that some 17,000,000 different combinations are possible at the time of the reduction division.[13] However, this does not cover all the possibilities, for there may be some interchanging by the process known as "crossing over."

A person who has a dominant abnormal trait is usually heterozygous. The abnormal person has one dominant, abnormal gene (A) and one recessive, normal gene (n) for the trait under discussion. The individual shows the pathologic trait because the normal gene is suppressed. Such an individual has the genotype (An). If this individual has children by a person without the abnormal trait, the following offspring result:

Parents	(An)		×	(nn)	
Germ cells	A	n		n	n
Offspring	(An)	(An)		(nn)	(nn)

One half of the offspring will be heterozygous and show the abnormal trait. The other half will be homozygous and normal.

Contrary to the rule just developed, a pathologic trait may apparently skip a generation. This may simply represent a very mild or "hidden" form of the trait which is not visible but can be transmitted in more apparent form through offspring. The reason for this apparent skipping

may be that environment was such as to suppress it for one generation. Or other genes may have a similar influence. As a single example of this type of hereditary pattern, one may mention familial hemolytic jaundice. In many members of a family a tendency to spherocytosis may be demonstrated, but only one or a few may demonstrate typical episodes of hemolytic crisis.

A heterozygous individual with an abnormal recessive gene may appear normal owing to dominance of the normal gene. However, if that person has offspring by another heterozygous individual, one fourth of the progeny will display the abnormality and three fourths will carry the abnormal genotype. Assuming N to be the normal dominant and p the abnormal recessive gene, the pattern of heredity will be:

Parents	(Np)		×	(Np)	
Germ cells	N	p		N	p
Offspring	(NN)	(Np)		(Np)	(pp)

Only the genotype (pp) will show the abnormality. It is much more likely for such a pairing of abnormal recessive genes to take place in consanguineous marriages than in normal marriages.

When a person who is homozygous for a pathologic trait marries a normal phenotype but heterozygous genotype for the same trait, one half of the children will be abnormal and the other half will appear normal but will be carriers of the recessive pathologic trait. Such an example follows:

Parents	(Np)		×	(pp)	
Germ cells	N	p		p	p
Offspring	(Np)	(Np)		(pp)	(pp)

Superficially such a family (two generations only) may appear to represent a pattern of a dominant pathologic trait such as the first diagram showed. Only a careful and complete study of more than two generations will reveal the true state of affairs.

If a homozygous normal (NN) marries a homozygous individual with abnormal recessive genotype (pp), all the offspring will appear normal but will carry the abnormal trait.

Hereditary characteristics may depend on the combined action of several genes. Owing to the laws of chance, the manifestations of an abnormal trait are diminished if it depends on several genes. One may thus see an abnormal child whose defect is determined genetically but whose family

appears entirely free from the specific defect. It should, therefore, be emphasized that a negative family history does not exclude a genetic determination of some abnormality.

It was previously mentioned that only 23 pairs of the human chromosomes are homologous. The remaining pair are the sex chromosomes. In the male these are unequal in size, the larger designated X and the smaller Y. In the female they are equal and both are termed X chromosomes. In reduction division in the male, one germ cell receives the X chromosome and one the Y chromosome. Fertilization may result in combination of X and Y and the production of a male, or the combination may be (XX), resulting in a female. Since the genes of the X chromosome in the male are not matched by an equal number of homologous genes in the smaller Y chromosome, the genes in the former are in a unique position to exert influence on the developing organism. Thus, recessive traits in the X chromosome of the male are not dominated by a corresponding gene in the Y chromosome. In the female such a recessive gene is usually overbalanced by its partner in the second X chromosome. Certain hereditary traits may therefore appear only in the male. Hemophilia and color blindness are well known examples of this pattern of sex-linked inheritance.

The poorly understood mechanism of mutation may explain certain congenital abnormalities. *Mutation* is defined as a permanent transmissible change in the character of an offspring from those of its parents. Such occurrences in human beings must be very rare and their etiology is obscure.

Although we have used as examples mainly pathologic traits, the same rules hold for variations of normal traits. Through the processes of blending and the additive effects of genes, each individual has a great tendency to follow a predestined pattern of growth and development which is very similar for all children. Although considerable variation does occur, the more or less common design which is inherited by the vast majority of persons is extremely important to realize. In studying the abnormal subject one is apt to forget the equally fascinating normal subject. The inheritance of the urge to grow normally and the over-all similarity of development among children have received little attention from a hereditary standpoint. The problem is indeed complex, but the implications are great.

The physical resemblance of families is too well known to merit extended comment. There exists a fairly high correlation with regard to stature and weight of siblings, and there is evidence that the rate of growth

is more alike among siblings than among nonrelated individuals. In certain families accelerated growth and early maturation are the rule; while in others the growth is slow and maturation is delayed. For stature, sitting height, head length and breadth, the correlation between monozygotic twins is higher than between fraternal twins and between siblings. These dimensions tend to "hold true" even when the twins are reared apart. Such a relation does not hold for weight.[11]

The search for size factors in mammals has shown that various genes are pleiotropic in their effects, affecting size as well as some other characteristic. There are some types of dwarfism and giantism in which inheritance is perfectly marked and definite.[4] (These are described in some detail in Chapter 13.) Most important for the physician to remember is that some children are small because of their genetic constitution and not because they have endocrine or nutritional disturbances, and that other children may be above average size or development because of heredity. In some cases only a careful study of the child and family will reveal that heredity can offer the only explanation for seeming abnormalities.

Apparently certain racial characteristics in growth and stature are largely, but not completely, on a genetic basis. Data collected during World War I in this country among the draftees revealed some interesting facts. It was found that the mean statures of Italians and Jews were the shortest, those of the Germans, English and Scots the tallest, while those of the French, Poles, Irish and Negroes were between these extremes. Further studies have shown that such differences are due to the rate of growth, for observations made at birth have revealed little significant difference in body dimensions among these racial groups, with the single exception of the Negro. At birth the Negro averages about 200 Gm. less weight and 2 cm. shorter length than the white infant. However, the subsequent pattern of growth in stature and weight are the same; the periods of acceleration coincide chronologically in the two groups.[11] In the case of the Negro one must be cognizant of difference in environment that plays an important role. Whether the same is true of the other races seems more difficult to prove.

Certain pathologic traits may modify growth and development to a great degree; indeed, this may be said of most of the truly pathologic traits. Some are of particular pertinence to this discussion and are listed here: osteogenesis imperfecta, certain of the chondrodystrophies, spina bifida, progressive muscular dystrophy of certain types, hereditary dwarf-

ism and hereditary giantism may be dominant pathologic traits; cystic fibrosis of the pancreas, Gaucher's disease, Niemann-Pick disease, amyotonia congenita, diabetes mellitus, some of the chondrodystrophies and microcephaly may all represent types of recessive pathologic traits; finally, some cases of ectodermal dysplasia with progeria appear as a sex-linked pathologic trait. Many cases of sexual precocity and abnormal growth pattern may be based on a genetic pattern, as previously suggested.[4, 15, 16]

The role of genetics in the development of mental characteristics is still a hotly debated subject. There can be little doubt that heredity plays an important part, but the organism is also strongly influenced by environment. At present, most child psychologists seem to support the view that heredity affects intelligence to a greater extent than does environment. In extreme situations, such as the individual constantly associated with feebleminded parents, environment may indeed cause lasting and irreparable damage to intellect. Emotional characteristics such as fear, wilfulness and temperament are probably more strongly influenced by environment than by heredity.[1]

PRENATAL ENVIRONMENT

It has been estimated that in the normal prenatal period 44 successive cell divisions take place and that an equivalent of only 4 additional divisions is necessary to change the newborn to adult size. The velocity of cell multiplication is particularly rapid in the first eight weeks, during which time the zygote is converted into the fetus, an organism possessing all of the essential features of an adult human being. Although the genes may be said to contain the plan of the future organism, this plan can be variously modified by environment. Differentiation, for instance, does not depend on genes alone. The type of cell developing in a certain part is determined by the close interaction of the nuclear material (containing the genes) with the internal (nucleus plus cytoplasm) and the external environments. Development consists of countless physicochemical processes. Whether the genes act as enzymes or catalysts, their normal mode of behavior depends on the presence of a normal cytoplasm and a normal external environment. So integrally related are inherent and environmental influences that it is impossible, except under controlled experimental conditions, to differentiate their respective contributions to the development of an organism.

Anomalies of the environment or of the genes may lead to faulty de-

velopment or to malformations. Certain genetic as well as environmental changes may, therefore, result in a very similar congenital defect. It should be emphasized that it is not a simple matter to classify a given congenital anomaly as "hereditary" or "nonhereditary." Between conception and birth the growing organism may be injured by many external factors. If injury occurs during the embryonic period the result is arrest of development and often irreparable malformation. During the fetal period (ninth week to birth) injuries result in changes more closely resembling those of postnatal damage such as mutilations and scars. Apparently the various organs are more sensitive to noxious agents at the time of rapid differentiation or maturation which occur during the embryonic period than they are later. The prenatal environmental factors listed here include most of those either proved to be or suspected of being harmful.[3, 4, 6, 14, 16]

1. Nutrition (deficiency of vitamins, iodine, possibly other factors).
2. Mechanical (amniotic bands, ectopia, abnormal fetal position, trauma, oligohydramnios).
3. Chemical toxins (a cause well established in animals but not in man).
4. Endocrine (diabetes mellitus, possible relationship to age of parents).
5. Actinic (roentgen rays, radium, etc.).
6. Infections (first trimester—rubella and possibly others; second trimester and thereafter—toxoplasmosis, histoplasmosis, syphilis, etc.)
7. Immunity (kernicterus due to Rh incompatibility).
8. Anoxia of embryo (faulty placental function).

Although there is no direct proof that vitamins influence human prenatal development, there are at least bits of experimental evidence that strongly suggest such a relationship. Warkany[16] has been able to produce congenital anomalies in animals by feeding the pregnant mothers diets severely deficient in certain vitamins. The types of malformation could be predicted by the omission of a specific vitamin. Other food elements have also been implicated by this investigator. In Chapter 3 we shall see that there is strong evidence that poor diet during pregnancy may result in a high incidence of stillbirths and neonatal deaths. That they are all due to anomalies of the fetus has not been conclusively shown, but the importance of proper maternal diet to normal intrauterine growth and development is established. Finally, it is known that when malnutrition becomes sufficiently severe conception is prevented altogether. In this regard one

might quote Warkany, who said: "The most serious congenital malformation is never to be conceived at all."

Mechanical factors, particularly abnormalities of fetal position and oligohydramnios, have been blamed for such congenital malformations as clubfoot, congenital bowing of the legs and micrognathia.[3] Such fetal anomalies are of relatively minor character or severity, probably because they have their pathogenesis late in intrauterine life. Faulty implantation of the ovum, which might be considered a mechanical factor, may interrupt the nutrition of the embryo, with resulting disturbance of development.

Although endocrine factors may harmfully affect the fetus, few well substantiated reports of such cases can be found in the literature. Endemic cretinism is more probably the result of an iodine deficiency in the maternal diet than the result of endocrine influence. Mothers suffering from hypothyroidism and Addison's disease have borne apparently normal children when under proper therapy. The pseudohermaphrodite is most commonly caused by excessive androgenic hormone production from its own adrenal cortex. The pathogenesis of this abnormal secretion remains unknown; it usually persists throughout childhood.

The newborn infants of diabetic or prediabetic mothers frequently display macrosomia, cardiomegaly, adrenal hyperplasia and extramedullary erythropoiesis with erythroblastosis. There may also be hyperplasia of the islets of Langerhans and resultant hypoglycemia. The infants often have respiratory difficulty and progress poorly during the neonatal period. Some of these conditions cannot be explained on the basis of hypoglycemia alone. They may be the result of abnormal endocrine influences on the fetus, nutritional disturbances on the basis of carbohydrate metabolism, genetic factors not yet clearly understood or may be the result of two or more of these factors in combination. The incidence of congenital malformations in children of diabetic mothers is about 10 times greater than the average.[8, 16]

The average age of mothers at the birth of mongolian idiots, and infants with some other anomalies, is significantly higher than that of mothers at the birth of normal children. We cannot at present give an adequate reason for this difference. It may be the result of the various endocrine changes that occur in women with advancing age, but other possibilities unrelated to the endocrine system may also be implicated.

Injudicious use of radium or roentgen ray therapy during pregnancy

has resulted in malformation of the fetus. Microcephaly, spina bifida, mental retardation and deformities of the extremities have been described in such instances.[16]

A tragic lesson concerning the effects of atomic radiation on the fetus was learned at Hiroshima, Japan.[18] If exposure to the atomic blast took place within the first 20 weeks of gestation and the mother was within 1,200 meters of the hypocenter, the chances of delivering a normal baby were indeed small. Seven of 11 mothers so exposed delivered children with diagnoses of microcephaly and mental retardation. Other anomalies in other fetuses less severely exposed because of greater distance from the hypocenter included congenital dislocation of the hip, congenital malformations of the eyes, congenital heart disease and mongolism.

Rubella (German measles) and possibly other virus and bacterial infections contracted by the mother in the early months of pregnancy can cause congenital heart disease, cataracts, deafmutism, mental retardation and microcephaly.[14] Congenital syphilis is an example of infection acquired by the fetus in utero that may affect both mental and physical growth. Prenatal toxoplasmosis may result in congenital macrocephaly or microcephaly and retinitis. Other examples of infections could be given, but those mentioned have particularly striking effects on the embryo or fetus.

Still another prenatal factor is the parity or order of birth of the child. This may affect its size at the time of delivery. The average birth weight increases with increasing order; i.e., the birth weight and linear dimensions of the firstborn are less than those of subsequent infants. The weight of infants of parity order 5 or more averages about 100 Gm. more than that of infants of parity orders 2-4. It is also well known that one of a pair of twins may be much smaller than the other at the time of birth whether they are identical or not.

In Chapter 3, on fetal growth and development, other important points not discussed here receive further consideration. We have attempted to show in the foregoing paragraphs that nothing is produced by the genes without intra- and intercellular factors playing an important role. Anyone desiring to understand completely the growth and development of children must be aware of this interesting field in which new observations are constantly modifying old concepts and perhaps pointing to new potentialities in the realm of practical therapeutics.

POSTNATAL ENVIRONMENT

Environment after birth may be varied in so many ways that well controlled studies are exceedingly difficult to make. Most of our knowledge is based on very gross differences that are easily apparent. Children vary in their potentialities for modification. These remain used or unused to the extent that the environment offers opportunity for their realization. As mentioned in Chapter 1, the human organism has a long period of immaturity which gives time for the development of many qualities, good and bad, necessary or detrimental to survival.

Children are not all alike and consequently we cannot expect exactly similar responses to similar changes in environment either in single individuals or in groups of individuals. Further, we know that the continuity of growth implies a resistance to displacement (both mental and physical) and a tendency to restoration of the normal pattern of development for a given child. An excellent example of this is shown by the premature infant. Early in life its measurements of physical growth are below those of the term infant, but in a relatively short time there is little difference between them and thereafter the growth of one parallels that of the other for all practical purposes. Differences in nutrition or environment may either speed up or slow down the period before equality is reached, but the tendency to convergence toward average trends will always hold.

Some of the more clearly understood environmental factors are discussed here; others are considered in the chapters that follow.

Geographic variations appear to be of little importance within the boundaries of the United States. Mills [9] has stated that children living in tropical regions show retarded growth and inferior adult size. However, since such children frequently suffer from poor diets and other poor socioeconomic factors, one can doubt that climate alone is responsible for the differences noted. Mills also found that full sexual maturity is reached later in the tropical and frigid zones than in the temperate zones.

There is considerable evidence to show that the growth rates of weight and height are influenced by the seasons of the year and that these differences are particularly striking in older children. Growth rates in weight are at a minimum in the spring and early summer and are maximal during late summer and autumn. Conversely, growth in height is greatest in the spring in this country.[11]

Measurements of infants born in a poor socioeconomic group are in general inferior to similar measurements of infants born in a high socio-

economic group. In many countries throughout Europe and in this country it has been shown that the stature of adult laborers is inferior to that of students, who presumably represent a more prosperous group. The rate of growth of children both of whose parents were unemployed was found to be inferior to that of children with one employed parent. Thus socioeconomic factors are of great importance in determining the physical status of children.[7, 10]

There is also an increasing accumulation of evidence that mental development is related to socioeconomic factors. The concept that some children are functioning at substandard levels because of faulty nutrition and other adverse environmental conditions is relatively new.[1] Whether actual intelligence is influenced or whether it is the ability to use the inherited potentialities that is affected remains to be proved. The important point introduced by several studies is that children's behavior should be interpreted with a knowledge of the interrelation of growth and organic development. As we will repeat again and again, significant advances in the study of child development can be made only with a careful correlation of all of the apparently isolated facts.

Recent studies have shown a general trend toward increase in height and weight of people in all of the civilized countries with each succeeding generation. Bowles[2] published data showing that in one American university sons were 1¾ in. taller and 10 lb. heavier than their fathers. Similar figures were found in comparisons of draftees of World Wars I and II. The cause of such changes has been attributed to one or more of the following: improved nutrition, better sanitation and medical supervision and, finally, to a smaller number of children in families.

In both man and animals the capacity for growth is great. If the rate of growth is retarded temporarily, as by illness, the total growth period will be lengthened. It also appears that man has some ability to adjust himself to a decreased food intake. If a child is held at a constant weight for a time by underfeeding he will again gain weight if the food intake is not further decreased. Such studies portray the tremendous impetus to growth and development despite adverse environmental conditions. They again emphasize the resistance to displacement from an average trend.[12]

Exercise may also be an important factor in the complete picture of development and growth. Growth processes are inseparable from dynamic processes, and physiologic activity of protoplasm favors its further development. The disuse atrophy and weakness of an immobilized limb are

examples of this important principle. The development of "skills" through practice might serve as still another illustration.

PRACTICAL APPLICATIONS

It is no longer believed that the child has inherited certain traits as finished products. What the child does inherit is a large assortment of genes which determine his make-up. Each of the many genes is a definite substance which influences some particular part of the developing embryo and child. From the time of conception until death each phase of development is influenced by the interplay of the inherited genes and the many environmental factors whose roles begin on fertilization. Growth, both mental and physical, is constantly creating its own new conditions as it proceeds. In appraising development we must consider all factors: family tree, cultural milieu, siblings, sickness, nutrition, sunshine, education and all the other possible influences.

Since a new combination of genes is formed with every child, there may be great diversity among siblings or between parents and the child. However, in general it may be stated that the child will show genetic characteristics similar to those of his relatives if he comes from a distinctly superior or inferior family. But there is no such thing as certainty in predicting the characteristics of children from knowledge of the family, with the possible exceptions of some of the congenital anomalies previously mentioned in which the mode of inheritance is known.[6]

If a child is born with a deficient genetic constitution, a change in environment will not go far toward improving him. On the other hand, individuals with superior gene combinations are precisely those who may take advantage of the opportunities which environment presents to them. Still other individuals seem to have inherited strong tendencies in particular directions. Here environment may have a good effect by assisting in the further development of the beneficial tendencies and/or repressing undesirable ones.

With increasing knowledge and improvements in technics more and more congenital anomalies are subject to remedy or improvement. However, therapeutic measures and environmental correction cannot cure defectiveness of genes. Nature's frequent remedy for this situation is to "neutralize" the defective genes by pairing them with normal genes from the other parent. The fact remains, however, that they are carried to future generations. The only method of preventing this is to prevent propagation

by the individuals who carry the defect. It can be seen that the problem becomes extremely complex when the pediatrician is confronted with a request for advice regarding adoption or advisability of parenthood. The interested reader should consult the references at the end of this chapter for further discussion of these very real problems.

Summary of the Factors Which Influence Growth

Genetics	This may influence the response of end organs to all sorts of stimuli, e.g., hormones, nutrients and external environment. In addition it may influence growth profoundly through congenital malformations of the end organ, as in achondroplasia.
Nutrition	This may include quantitative and qualitative amounts of the building materials, i.e., protein, carbohydrate, fats, minerals and vitamins. Nutrition may also be influenced by diseases of the gastrointestinal tract, e.g., diarrhea and celiac disease. Finally, local or general nutritional failure may result from circulatory changes such as congenital heart disease.
Internal milieu	Optimal growth presupposes normal function of all organs and normal metabolism. Severe liver or kidney insufficiency are examples of conditions that preclude normal growth due to impairment of tissue metabolism of all parts of the body.
Hormones	Secretions of the endocrine glands act as catalysts to the normal growth potentials of the body. Some are growth-promoting, as the pituitary growth-stimulating hormone and androgens. Others cause maturation—thyroid hormone, androgens and estrogens. Some may be antagonistic to growth but useful in other ways when in proper balance—the adrenal cortical 11-oxysteroids.
Environment	Exposure to disease can influence ultimate growth. There are definite seasonal variations in increments of weight and height. Climate may also influence maturation. Emotional disturbances may affect growth, e.g., anorexia. Socioeconomic aspects may be important in relation to nutrition, clothing, disease, etc. Such factors as fetal position, faulty implantation of the ovum, rubella during pregnancy, etc.,

are among the earliest adverse environmental influences on the growing organism.

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3

Fetal Growth and Development

FETAL GROWTH

THAT GROWTH AND DEVELOPMENT do not begin at the time of birth is quite obvious, but for the pediatrician birth marks the onset of growth and development from a clinical standpoint. To provide a clear understanding of these phenomena after birth, the changes that occur before birth and continue to take place in the postnatal period are reviewed here.

Life as a new individual commences at the moment of fertilization. Growth becomes an inherent force in that individual and continues, in stature at least, until the average postnatal age of about 20 years unless disease or accident or death interferes. During this time there are also marked changes in differentiation or maturation of specific organs as well as in the body as a whole.

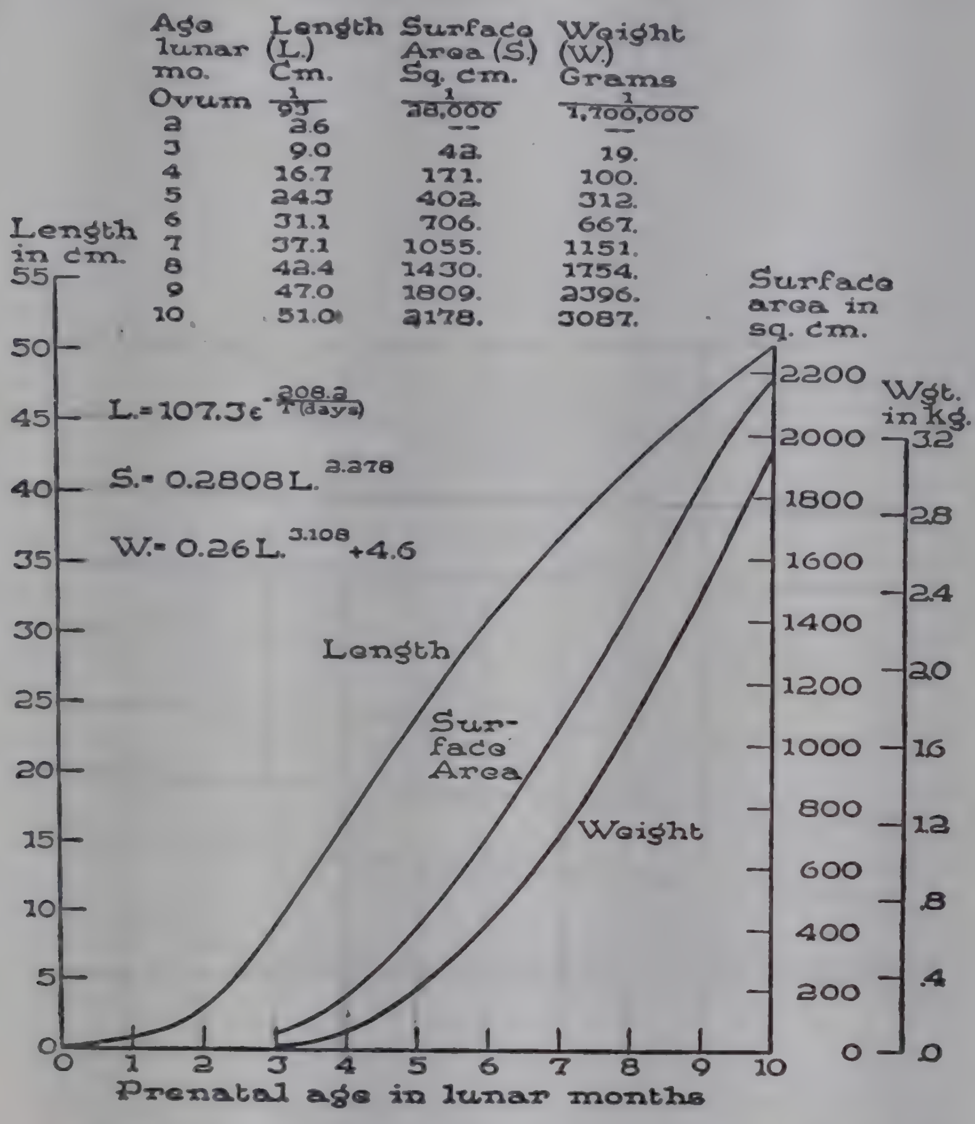
Figure 1 shows the curves for height, surface area and weight for a normally developing fetus. The steepness of the curves is better appreciated when it is realized that growth is plotted by monthly increments rather than by yearly increments as commonly done for the postnatal period. During the second month, the embryo tends to grow about 1 mm. a day in "sitting height" and thereafter averages 1.5 mm. per day.[9] In comparison, a 10 year old child who had continued to grow at the rate of 1.5 mm. a day would be 20 ft. tall.

The increase in weight is even more surprising. From birth to maturity the weight is increased twenty-fold. From the time of fertilization to birth the increase in weight is approximately 6 billion times.

Wetzel's graphs (pp. 66 ff.) show that the rate of growth of total body mass constantly increases during intrauterine life, and for several years after birth the curve of growth shows a steady decline. Maxi-

mal linear growth during gestation occurs at the sixth and seventh months and decelerates during the last two months of the fetal period.[10]

Figure 2 shows the relative proportions of different parts of the body during fetal and postnatal life and portrays the changes taking place with growth better than any written discussion. It is not until the third month



Age lunar mo.	Length (L.) Cm.	Surface Area (S.) Sq. cm.	Weight (W.) Grams
Ovum	1/99	1/28,000	1/1,700,000
2	2.6	--	--
3	9.0	42.	19.
4	16.7	171.	100.
5	24.3	402.	312.
6	31.1	706.	667.
7	37.1	1055.	1151.
8	42.4	1430.	1754.
9	47.0	1809.	2396.
10	51.0	2178.	3087.

$L. = 107.3 e^{-\frac{208.2}{T\,(\text{days})}}$

$S. = 0.2808 L.^{2.278}$

$W. = 0.26 L.^{3.108} + 4.6$

FIG. 1.—Curves of prenatal growth: length (crown-heel), surface area of the body and weight from time of conception to birth. (From Patten, B. M.: *Human Embryology* [Philadelphia: Blakiston Company, 1946]; after Edith Boyd.)

that the fetus definitely resembles a human being. The head is disproportionately large and the umbilical herniation is reduced due to the return of the intestine into the abdominal cavity. The nails are forming and sex can be determined. At 5 months hair is present on the head and body and shortly thereafter eyebrows and eyelashes form. At 7 months the fetus looks like a dried-up old man with red and wrinkled skin. The eyelids

are no longer fused. By the eighth lunar month subcutaneous fat begins to accumulate and the nails are completely formed. The major changes from this time until birth are due to progressive accumulation of fat, and the downy hair coat is shed.[1, 9, 10]

In the following chapters will be found brief references to fetal organ development, and they will not be repeated here. By the end of the second fetal month definition of the permanent organs is so far advanced that the subsequent growth of the fetus is devoted to the development of parts al-

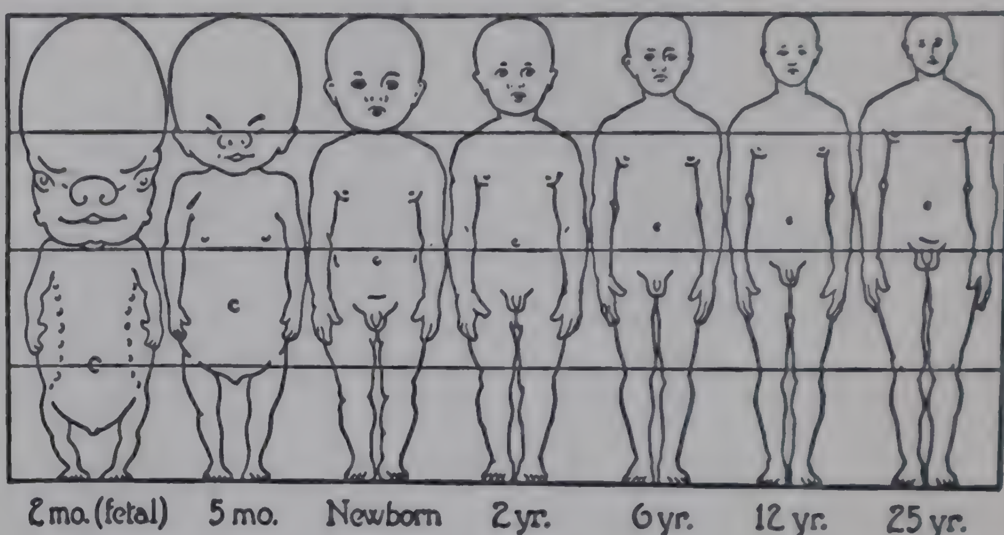


FIG. 2.—Stages of growth—relative proportions of head, trunk and extremities for different ages. (From Robbins, W. J., *et al.*: *Growth* [New Haven, Conn.: Yale University Press, 1928].)

ready formed. In general, the growth of organs during prenatal life follows an accelerating smooth curve which is in marked contrast to the divergent growth curves following birth (see Fig. 23, p. 174). Some aspects of human fetal development are outlined in the following tabulation from Arey.[1] The figures in parenthesis refer to fetal age in lunar months.

Integument	Three-layered epidermis (3)
	Body hair begins (4)
	Skin glands form, sweat and sebaceous (4)
Mouth	Lip fusion complete (2)
	Palate fused completely (3)
	Enamel and dentin depositing (5)
	Primordia of permanent teeth (6–8)
Gastrointestinal	Bile secreted (3)
	Rectum patent (3)

	Pancreatic islands appear (3)
	Fixation of duodenum and colon (4)
Respiratory	Definitive shape of lungs (3)
	Accessory nasal sinuses developing (4)
	Elastic fibers appear in lung (4)
Urogenital	Kidney able to secrete (2½)
	Vagina regains lumen (5)
	Testes descend into scrotum (7–9)
Vascular	Definitive shape of heart (1½)
	Heart becomes four-chambered (3½)
	Blood formation in marrow begins (3)
	Spleen acquires typical structure (7)
Nervous	Commissures of brain complete (5)
	Myelinization of cord begins (5)
	Typical layers of cortex (6)
Special senses	Nasal septum complete (3)
	Retinal layers complete, light-perceptive (7)
	Vascular tunic of lens pronounced (7)
	Eyelids open (7–8)

FETAL BEHAVIOR

Behavior depends to a great extent on morphology and structure, and one cannot discuss behavior without also discussing developmental anatomy. There are regulating growth mechanisms which govern the order in which successive patterns of behavior emerge. Most fundamental are the structures of the muscle and nerve cells and the manner in which these structures come into functional relationship.

Fetus at 8 Weeks

The major components of both trunk and limb musculature are evident in the embryo at the end of the second fetal month.[6] The nerves as yet have no anatomic nor physiologic connections with either smooth or striated muscle. During this time the embryo has floated quiescently in the amniotic fluid. However, movement has already taken place in this new individual. Since 4 weeks of age the heart has been beating at a fairly regular rate.[16] Skeletal muscle may have developed an intrinsic tonus by this time also. The available evidence indicates that the fetus becomes capable of responding to tactile stimulation at 8½ weeks. The trunk flexes

and the head extends. Anatomically, by this time, there are found all of the necessary components of the reflex arc.[6]

Fetus at 12–14 Weeks

With increasing age and maturation of the neuromuscular system the movements spread caudally and become more pronounced in the lower trunk. Then discrete reflexes appear, accompanying spread of the skin areas sensitive to stimulation. By 14 weeks the human fetus has largely ceased to exhibit the earlier more generalized responses and activity becomes less stereotyped.[6]

Windle[16] has stated that behavior, in general, goes through five stages: (1) myogenic responses; (2) neuromotor responses; (3) reflex responses; (4) integration of simple reflexes; (5) integration and control from higher centers. From this it can be seen that behavior follows closely the differentiation of structures in the fetal nervous system. Evidence concerning the functions of the central nervous system during prenatal life indicates that behavior, until about the beginning of the sixth month, is largely controlled by spinal mechanisms.[8] At a slightly later period there are indications that the medulla and lower brain centers participate in the control of specific reflex activities. (It is possible that a strong stimulus may affect the medulla before this, however, as indicated by the respiration-like movements which may occur at 20 weeks.) There is no evidence that the cerebral cortex exerts any specific influence on behavior until some time after birth.[8]

By the end of the first trimester the fetus makes brief jerky movements without artificial stimulation. By the twentieth week the sucking reflex is present and the first patterns of respiratory movements manifest themselves.[5, 16]

Fetus at 28 Weeks (Viable)

The fetal age of 28 weeks approximately demarcates the zone between viability and nonviability. The following outlines of behavior are based on the observations of Gesell[5] in premature infants from fetal ages of 28 to 40 weeks. He states that this behavior probably varies only slightly from that which would take place in utero. To support this contention he was able to demonstrate: (1) that all infants of the same fetal age follow a very similar pattern of behavior, (2) that, in general, the week old neonate exhibits a behavior picture remarkably like that of the mature "fetal-infants,"

and (3) from previous studies, that in older premature infants the fundamental rates and patterns of development are little disturbed by displacements of birth.

Fetus at 28–32 Weeks

Movements meager, fleeting, poorly sustained
Lack of muscular tone
Mild avoidance responses to bright light and sound
In prone position turns head to side
Palmar stimulation elicits barely perceptible grasp
Breathing shallow and irregular
Sucking and swallowing present but lack endurance
No definite waking and sleeping pattern
Cry may be absent or very weak
Inconstant tonic neck reflex

Fetus at 32–36 Weeks

Movements sustained and positive
Muscle tone fair under stimulation
Moro reflex present
Strong but inadequate response to light and sound
In prone position turns head, elevates rump
Definite periods of being awake
Palmar stimulation causes good grasp
Good hunger cry
Fairly well established tonic neck reflex

Fetus at 36–40 Weeks

Movements active and sustained
Muscle tone good
Brief erratic following of objects with eyes
Moro reflex strong
In prone position attempts to lift head
Active resistance to head rotation
Definite periods of alertness
Cries well when hungry and disturbed
Appears pleased when caressed
Hands held as fists much of time, good grasp
Tonic neck reflex more pronounced to one side (usually right) than to the other
Good, strong sucking reflex

Each infant in Gesell's series showed individuality as well as a general sameness of over-all behavior pattern. It can be seen that the development of fetal behavior lays a necessary foundation for the later development of postnatal behavior, the latter not merely being imposed on the former but arising from it by a process of maturation of existing activities.

METABOLISM OF THE FETUS

One of the greatest changes that the newborn individual must make is in the regulation of his own body temperature. In utero the fetal temperature is well controlled by the maternal environment and fluctuations must be minimal. Consequently the fetus is called on to produce little heat because there are little activity, depressed muscle tone and insulation against heat loss. Figures on fetal metabolism are understandably difficult to obtain but, in general, they indicate a lower rate than that of the newborn.[12, 16]

NUTRITION OF THE FETUS

The normal physiologic processes of the body are greatly altered during pregnancy, and additional demands are imposed on the maternal organism during this period. It is well established that the state of maternal nutrition influences the nutrition and consequently the growth and development of the child. [2–4] If the need arises, the fetus is to a certain extent provided for at the expense of the mother. When the maternal intake of iron, calcium or phosphorus, as examples, is inadequate the fetus draws on her reserves to supply its own requirements. A very low iron or calcium intake by the mother may produce anemia or poor bone formation, respectively, in the child, especially if this occurs during the final trimester. A severe reduction of the protein intake, as in starvation, will lead to a lower than average weight and length of the newborn.[2] When the starvation is sufficiently severe, abortion, stillbirth or sterility may result. Burke and Stuart,[3] Ebbs[4] and others[13] have studied the effect of diet on the fetus. They concluded that infants born to mothers on excellent or good diets (based on caloric, protein, vitamin and mineral intake) during pregnancy were superior in general health and vigor to infants born to mothers on poor diets. In the Burke and Stuart series, every stillborn infant, all but one of those that died in the neonatal period, most of the infants with marked congenital defects, all premature and all "functionally immature" infants were born to women whose diets were very inadequate. Ebbs cited

an example from a study carried out in England where the number of stillbirths and neonatal deaths was reduced by 43 per cent in a group of women given adequate diets as compared with another group in every way similar except for diet.

The "calcium rating," as determined by tooth and osseous development, is superior in children born of mothers on "excellent diets" as compared with those born of mothers on "poor diets." In addition it has been shown that there is a close relationship between the birth weight and length of children and the quantity of protein in the maternal diet. Few long-term studies have been carried out to see what effect the poor diet during pregnancy has on subsequent growth and development of the child. In one such study, however, the incidence of infections (bronchitis, pneumonia and colds) during the first six months was significantly higher in the lower rated group. Also, the incidence of anemia was higher in infants born to mothers on a poor diet.[2, 3]

The effect of specific vitamin deficiencies is not so well known. There have been isolated reports of infants born with beriberi,[15] rickets[3] and scurvy.[7] As mentioned previously, Warkany produced congenital malformations of the eyes and other tissues in animals by depriving the mother of vitamin A. He has also shown a relationship between riboflavin deficiency in the rat and certain congenital skeletal defects.

Finally, it should be pointed out that an adequate diet will reduce the complications of pregnancy in the mother. In the English study cited by Ebbs,[4] the incidence of toxemia of pregnancy was reduced 30 per cent in the group on a supplemented diet. The incidence of less severe complications such as nausea and vomiting was similarly reduced. These are important factors to consider, because they are known to affect the fetus to a greater or lesser extent.

It may be concluded that the pregnant woman requires more calories, minerals, vitamins and protein than the nonpregnant woman to insure proper or optimal growth of the fetus.

In the human being the yolk sac has little function as a source of nutrition for the fetus. The placenta is the sole source of respiration, excretion* and nutrition for the new individual. The body of the fetus is built and nourished from the substances available in the mother's blood, the most readily available of which is dextrose. The placenta and liver of

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*The amniotic fluid may serve the fetus as a means of excretion, for there is some evidence to show that this fluid is fetal in origin.

the fetus are important depots for carbohydrate storage, and as the liver becomes more active in storing glycogen there is a corresponding reduction of storage in the placenta. The glycogen content of the fetal liver rises rapidly toward the end of gestation and is maintained to some extent at the expense of the maternal carbohydrate metabolism.[16]

Lipids cannot readily pass from the maternal organism to the fetus owing to the placental barrier. It may be postulated, therefore, that most of the fetal lipids are synthesized in the body of the fetus. Both fetal and newborn fats differ from fats found in the more mature subject, having a higher melting point (in the fetus) and degree of saturation and containing more palmitic acid but less oleic and stearic acids. Regardless of the type of fat fed the mother, fetal fat has an almost unalterable degree of saturation. Blood lipid levels are always below those of the mother.[16]

The fetus stores the major portion of its proteins during the last trimester. The maternal and fetal blood levels of nonprotein nitrogen, urea and uric acid are nearly identical near term. The amino acid levels near term are higher in fetal than in maternal blood. The total serum protein content of the fetus is constantly lower than that of the mother, the lowest value being that for the globulin fraction.[16] It is probable that some of the protein is produced or modified by the fetus and is not simply stored maternal protein.

Available knowledge of mineral metabolism indicates that little demand is made on the mother until the last three months of gestation. These minerals are further considered in Chapter 11, on nutrition in normal growth.

INTERNAL ENVIRONMENT

As growth progresses the relative content of the total body water decreases. The 6 week old fetus contains about 97 per cent water, the newborn about 74 per cent and the adult about 72 per cent. With the loss of water there results a proportionate loss of sodium and chloride (Fig. 3). The reduction of fluid content of the body is due almost entirely to a reduction of extracellular fluids. Since the concentration of sodium and chloride in the extracellular fluid is the same for the fetus, the newborn infant and the adult, the total body content of these minerals changes with growth in order to maintain this even concentration. The percentage of total body content of chloride is: fetus, 0.27; newborn, 0.25; adult, 0.21.[11]

With the increase in tissue mass that occurs with growth there is an

increase in the total amount of intracellular fluid. To maintain ionic and osmotic equilibrium, the increase in potassium content of the body parallels the increase in intracellular fluid. Table 1 shows these changes. The sodium

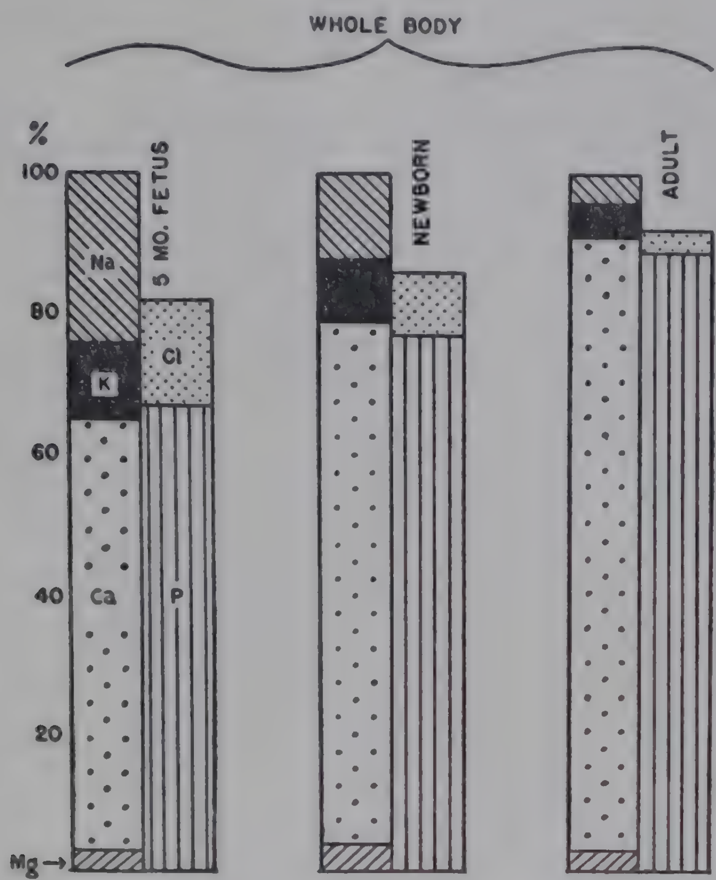

FIG. 3.—Total mineral content of the body at different periods of development; trace elements are not represented. The apparent excess of positive ions is compensated for by organic acids and protein. (From Shohl, A. T.: *Mineral Metabolism* [New York: Reinhold Publishing Corp., 1939].)

TABLE 1.—CHANGES IN DISTRIBUTION OF WATER AND POSITIVE IONS THROUGHOUT LIFE

	TOTAL BODY WATER		TOTAL BODY FLUID	
	Na^+, mEq./kg.	K^+, mEq./kg.	Extra-cellular, %	Intra-cellular, %
Fetus	125	52	71	29
Newborn	97	63	63	37
Adult	67	95	42	58
Adult (corrected for intracellular sodium)			30	70

and potassium ion concentrations are given for the whole body. The percentages of extracellular and intracellular water are computed on the basis that the sodium is entirely extracellular and the potassium intracellular.[11]

The sum of the two cations in the total body fluids equals approximately 162 mEq./kg. of water throughout life. These figures show that as growth continues and the number of cells increase, an ever-increasing amount of water becomes intracellular.

PRACTICAL APPLICATIONS

Growth and development have progressed to a considerable degree before birth. All of the organ systems are well established by the second fetal month and at no time after birth is growth as rapid as during the prenatal period. Through an understanding of fundamental embryology a better concept of congenital anomalies is obtained as well as an appreciation of future trends in growth and development. We have seen that most of the vital reflexes are well established and prepared for the initial shock of extrauterine existence. Behavior depends on functional and morphologic development and is influenced by regulating growth mechanisms which determine the pattern of behavior both pre- and postnatally. Behavior may well be a better criterion of the degree of maturity than physical measurements during the neonatal period.

The importance of maternal nutrition during pregnancy has been stressed because there is little doubt that this factor influences the development of the fetus and the well-being of the organism for some time after birth. A better knowledge of the physicochemical changes that take place just before and after birth will aid us in further reducing neonatal mortality.

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4

Normal Physical Measurements

The relationship of the rate of growth and adequacy of body development to physical fitness is generally recognized. By comparison of the physical measurements of a given child over a period of time with those of other healthy children it is possible to determine, within limitations, whether he is doing as well as should be expected. The purpose of this discussion is to present normal body measurements and charts illustrating their use in the evaluation of progress of normal growth. It should be kept in mind that such measurements are made to reinforce and improve clinical judgment and not to displace it.

In the recent literature on measurements of children it has become common practice to use one of two different standards as a means of assigning a given individual some point of reference relative to the group of his age. One method uses a mean value and one or more standard deviations. Such a system of presenting figures gives a good indication of just where a given child is in relation to the so-called normal group. One standard deviation includes 66.6 per cent of the total number, two standard deviations includes 95 per cent and three includes 99.7 per cent. Many of the tables presented here are given in this form. The other method of presenting such data is in percentiles. The number of the percentile indicates the position which a measurement would hold in a typical series of 100 (100 per cent). Thus the 10th percentile gives the value for the tenth child of a group of 100. Nine children will be smaller in the measurement under consideration and 90 will be larger. At the 50th percentile an equal number of children will be smaller or larger than the measurement. Table 2, for height and weight, was constructed according to this method. Both the percentile and the standard deviation method are of value in estimating where a given child stands relative to a large group of the same age and

TABLE 2.—PERCENTILES FOR WEIGHT AND HEIGHT OF AMERICAN CHILDREN*

Percentiles, Boys 10	50	90	Age Measurement	Percentiles, Girls 10	50	90
			Birth			
6.3	7.5	9.1	Weight, lb.	6.2	7.4	8.6
18.9	19.9	21.0	Length, in.	18.8	19.8	20.4
			3 mo.			
11.1	12.6	14.5	Weight, lb.	10.7	12.4	14.0
22.8	23.8	24.7	Height, in.	22.4	23.4	24.3
			6 mo.			
14.8	16.7	19.2	Weight, lb.	14.1	16.0	18.6
25.2	26.1	27.3	Height, in.	24.6	25.7	26.7
			1 yr.			
19.6	22.2	25.4	Weight, lb.	18.4	21.5	24.8
28.5	29.6	30.7	Height, in.	27.8	29.2	30.3
			2 yr.			
24.7	27.7	31.9	Weight, lb.	23.5	27.1	31.7
33.1	34.4	35.9	Height, in.	32.3	34.1	35.8
			3 yr.			
28.7	32.2	36.8	Weight, lb.	27.6	31.8	37.4
36.3	37.9	39.6	Height, in.	35.6	37.7	39.8
			4 yr.			
32.1	36.4	41.4	Weight, lb.	31.2	36.2	43.5
39.1	40.7	42.7	Height, in.	38.4	40.6	43.1
			5 yr.			
35.5	40.5	46.7	Weight, lb.	34.8	40.5	49.2
40.8	42.8	45.2	Height, in.	40.5	42.9	45.4
			6 yr.			
40.9	48.3	56.4	Weight, lb.	39.6	46.5	54.2
43.8	46.3	48.6	Height, in.	43.5	45.6	48.1
			7 yr.			
45.8	54.1	64.4	Weight, lb.	44.5	52.2	61.2
46.0	48.9	51.4	Height, in.	46.0	48.1	50.7
			8 yr.			
51.2	60.1	73.0	Weight, lb.	48.6	58.1	69.9
48.5	51.2	54.0	Height, in.	48.1	50.4	53.0
			9 yr.			
56.3	66.0	81.0	Weight, lb.	52.6	63.8	79.1
50.5	53.3	56.1	Height, in.	50.0	52.3	55.3
			10 yr.			
61.1	71.9	89.9	Weight, lb.	57.1	70.3	89.7
52.3	55.2	58.1	Height, in.	51.8	54.6	57.5

*These figures are abbreviated and modified from data of H. C. Stuart, Department of Maternal and Child Health Harvard School of Public Health, and H. V. Meredith, Iowa Child Research Station.

It can be seen that with increasing age, the measurements lie farther apart for each of the given percentiles. Additional tables presenting the anthropometric data of Stuart and Meredith are given on pages 54-57.

TABLE 2.—PERCENTILES FOR WEIGHT AND HEIGHT *(cont.)*

			12 yr.			
72.0	84.4	109.6	Weight, lb.	69.5	87.6	111.5
56.1	58.9	62.2	Height, in.	56.1	59.6	63.2
			14 yr.			
87.2	107.6	136.9	Weight, lb.	91.0	108.4	133.3
59.9	64.0	67.9	Height, in.	60.2	62.8	65.7
			16 yr.			
111.0	129.7	157.3	Weight, lb.	100.9	117.0	141.1
64.1	67.8	70.7	Height, in.	61.5	63.9	66.5
			18 yr.			
120.0	139.0	169.0	Weight, lb.	103.5	119.9	144.5
65.5	68.7	71.8	Height, in.	61.5	64.0	66.7

sex. In some of the material presented in this chapter neither method has been used because the group studied was too small to give reliable trends or it was believed that these technics would add little of value to simple averages from a purely practical standpoint.

It is difficult to select truly representative figures of measurements in children. Many of the tables commonly used as acceptable standards are out of date so far as today's children in this country are concerned. The Baldwin-Wood Tables are an example. They are based on measurements made over a generation ago. Some figures are of doubtful value because of the inadvertent selection of subjects used for the study, e.g., children from a special socioeconomic group or from a limited geographic area. Furthermore, there are few studies pertaining to racial groups or to one race in different environments. The use of standards such as those outlined in the foregoing paragraph does not rule out the objection that such tables are usually compiled from a more or less polyglot population in which many of the individuals are below optimal development. The tables used here are from relatively recent sources and represent measurements of children reared under relatively satisfactory conditions. Within the boundaries of the United States they can probably be considered adequate for clinical purposes. The interested reader might consult more detailed articles and monographs on the subject.[11, 15, 16, 24]

INDIVIDUAL GROWTH PATTERNS

When growth and development status or level of a given child is being appraised, the physician must keep in mind that this child like all others has his own growth pattern. His growth will resemble that of other children but his timetable is strictly his own. For this reason mean or

average values for height and weight should not be considered more than points of reference. When sequential measurements can be made, the percentile method of recording height and weight are much more useful than tables stating means and standard deviations. It is more important to know that a child is consistently maintaining a given relationship (in height and weight) to other children of his sex and age than it is to know that he is tall or short. The progress of growth (height and weight) is predictable for a given child once his approximate percentile position or channel is established. Deviation from his channel is more noteworthy than the actual percentile relationship. Figures 4*C* and 4*D* (pp. 62 and 63) show the percentile method of recording measurements.

GENERAL BODY CONFIGURATION

Alteration of body configuration results from selective regional rate of growth at different stages during the developmental period. In infancy the head grows at a relatively rapid rate so that during the first year the head circumference is greater than that of the chest. Thereafter, the chest circumference becomes increasingly larger in proportion, since growth of the head after the first year is slow. Some exceptions to this rule may normally exist, and for this reason absolute measurements of the head have greater value than do proportions. The extremities are shorter than the trunk at birth but grow more rapidly later. During adolescence the major gain in height is due to growth of the lower segment of the body; however, growth of the legs slows and ceases somewhat sooner than that of the trunk.[22] The ratio of the distance from crown to symphysis to that from symphysis to sole of the foot relates the trunk-extremity proportion. This proportion decreases from approximately 1.7 at birth to near unity at 10 years and is thereafter maintained. The adult male has relatively longer extremities than the adult female.

During most of childhood growth appears to be primarily linear. In the adolescent, growth assumes more of a process of "filling out." Linear growth does not cease entirely until maturity is reached, at about 18 years in girls and 20 years in boys. However, after a rather short period of linear growth at puberty, linear increase diminishes quite abruptly and tapers off to an insignificant amount by about 16 years in girls and 18 years in boys. For purposes of predicting eventual height in the early-maturing girl, it can be stated that growth in height is seldom more than 2 in. after menarche. During adolescence girls show an increase in breadth

relative to height from about 11 years, whereas boys maintain a relatively constant ratio.[22] These changes are easily demonstrated by use of the width-length index, obtained by dividing the pelvic bicristal diameter (pelvic breadth or intercristal width) by the standing height (Table 3). (It has also been stated that this index is one of the most reliable measures for estimating body build or physique.[9]) On the other hand, shoulder breadth is found to expand more rapidly in boys than in girls. These and

TABLE 3.—Width-Length Index for Boys and Girls at Different Ages*

Age	Boys	Girls
Under 1 year	0.173	0.175
1 year	.168	.172
3 years	.166	.168
5 years	.161	.161
7 years	.159	.159
9 years	.157	.159
11 years	.157	.161
13 years	.156	.163
15 years	0.155	0.164

*From Lucas and Pryor.[9] The figures express the mean for normal subjects.

other differences in rates of growth account for the differences in average size, physique and contour between the sexes in adult life.

Longitudinal studies have demonstrated that children pass through the phase of accelerated growth associated with adolescence at widely different chronological ages, but that they follow the same pattern or sequence for any particular measurement. In general, the sooner the phase is entered the sooner growth (in height and weight) is completed. Children who enter the period early are apt to be slightly shorter as adults than are those who enter the period later. The stimulus to advanced or retarded growth is a general one and affects all dimensions.

Some of the many different measurements suggested for proper evaluation of growth in children have considerable importance to the research worker. A volume which purports to be brief and practical is of necessity selective, and the measurements included in this chapter are believed to represent the most significant ones because experience has shown them to be most reliable. They are based on easily accessible bony landmarks and therefore are least subject to errors of interpretation or to variation of muscle tonus. In addition to linear or weight measurements alone, various authors have used indexes in an attempt to demonstrate body proportions better. Two examples have been given: the trunk-extremity proportion

and the width-length index. Both may be useful in determining certain factors in the maturation of children. As a single example, it is known that the trunk-extremity index remains high in untreated children with hypothyroidism; i.e., infantile proportions are maintained. Other useful indexes are referred to at various points in the discussion which follows.

PHOTOGRAPHY

Good photographs may be of considerable aid as an accessory in growth studies. The graphic record of change afforded by photographs of a subject often portrays points difficult to show by figures, description or curves. Such photographs should be made with the subject nude, in anterior and lateral views, with a measured grid as a background that will show up well in the print. The child should stand as close as possible to the grid to avoid large errors from parallax. If the camera is high, near the eye level of the subject, the error due to parallax is minimized for those attempting to read actual height directly from the background grid.

HEAD MEASUREMENTS

One of the most important measurements is the circumference of the head because it is related to the intracranial volume and permits an estimation of the rate of brain growth. It is a measurement having a relatively narrow normal range for an age group. Any disturbance in the growth of the brain or injury to it may result in such varied clinical conditions as microcephaly and hydrocephaly. During the earlier months of life, when maturation of the brain proceeds at a rapid rate, it may be easier to detect such anomalies from abnormalities of the head size than from evaluation of the subject's performance level. Often the clinician is misled by visual inspection, and it is not uncommon for one to suspect hydrocephaly in a premature infant when accurate measurements will dissipate such fears.[4] It is in such subjects that the proportions between head and chest may be misleading; direct measurements of the head are of greater value than such relationships.

Head circumference is measured by passing a tape measure over the most prominent part of the occiput and just above the supraorbital ridges. At birth the circumference is close to 13.75 in. (35 cm). A normal variation of ½ in. (1.2 cm.) above or below that value may be present in more than half of normal full term infants.[4] There is about a 2 in. (5 cm.) increase in the first four months of life, or about ½ in. a month, and

another 2 in. increase in the next eight months, making a total growth of slightly over 4 in. (10 cm.) for the first year. Thereafter, the circumference increases at a rapidly decelerating rate. From the end of the first year to the age of 20 there is only a 4 in. increase (Table 4).

Another measurement commonly used for obstetric purposes and to estimate the degree of maturity at birth is the occipitofrontal diameter. The range for full term infants is 4–5.5 in. (10.5–12.9 cm.). Owing to

TABLE 4.—Average Head Circumference of American Children*

Age	Mean		Standard Dpviation	
	In.	Cm.	In.	Cm.
Birth	13.8	35	0.5	1.2
1 month	14.9	37.6	0.5	1.2
2 months	15.5	39.7	0.5	1.2
3 months	15.9	40.4	0.5	1.2
6 months	17.0	43.4	0.4	1.1
9 months	17.8	45.0	0.5	1.2
12 months	18.3	46.5	0.5	1.2
18 months	19.0	48.4	0.5	1.2
2 years	19.2	49.0	0.5	1.2
3 years	19.6	50.0	0.5	1.2
4 years	19.8	50.5	0.5	1.2
5 years	20.0	50.8	0.6	1.4
6 years	20.2	51.2	0.6	1.4
7 years	20.5	51.6	0.6	1.4
8 years	20.6	52.0	0.8	1.8
10 years	20.9	53.0	0.6	1.4
12 years	21.0	53.2	0.8	1.8
14 years	21.5	54.0	0.8	1.8
16 years	21.9	55.0	0.8	1.8
18 years	22.1	55.4	0.8	1.8
20 years	22.2	55.6	0.8	1.8

*Based on several recent sources, including Stuart and Simmons.

molding coincident to labor, much variation can result, and such measurements have less value in growth studies during the neonatal period. At 1 year this diameter is 6.5 in. (16 cm.), at 2 years 7 in. (17 cm.) and at 18 years approximately 8 in. (19 cm.).

The shape of the adult head differs conspicuously from that of the infant, the cranium being much more prominent in the latter. Separation of the cranial bones during the neonatal period is not uncommon, nor is a slight degree of overlapping. It might be added that in abnormally shaped skulls (oxycephaly, scaphocephaly, brachycephaly), none of the measurements given will indicate the true volume of the cranial vault.

CHEST MEASUREMENTS

Measurements of the chest should be taken with the subject recumbent at the level of the nipples midway between inspiration and expiration.

Mean values are given in Table 5. At birth the transverse and anteroposterior diameters are nearly equal. The thoracic index, which is the ratio of the former to the latter, at this time is 1.0. The transverse diameter increases

TABLE 5.—AVERAGE CHEST CIRCUMFERENCE AND INTERCRISTAL WIDTH OF AMERICAN CHILDREN

Age	Chest Circumference		Pelvic Bicristal Diameter	
	In.	Cm.	In.	Cm.
Birth	13.7	35	3.2	8
3 months	16.2	40	4.3	11
6 months	17.3	44	4.8	12
1 year	18.3	47	5.1	13
18 months	18.9	48	5.5	14
2 years	19.5	50	6.0	15
3 years	20.4	52	6.2	16
4 years	21.1	53		
5 years	22.0	55	7.2	18
6 years	22.5	56		
7 years	23.0	57	8.2	20
8 years	24.0	59		
9 years	24.5	60	8.5	21
10 years	25.1	61		
12 years	27.0	66	9.0*	22*
14 years	29.0	72		
16 years†	31.0	77		
18 years†	33.0	82		
20 years†	34.5	86		

*Over age 12 there is wide variation. †Males only.

more rapidly than the anteroposterior, so that at 1 year the index is 1.25 and at 6 years 1.35. The ratio changes little thereafter.

ABDOMINAL AND PELVIC MEASUREMENTS

During infancy and early childhood the abdomen is more prominent than at subsequent ages. The circumferences of the abdomen and thorax are about equal until 2 years; after this time the abdominal circumference is considerably less than the thoracic. Because the abdominal circumference is influenced by the phase of respiration, the degree of voluntary and involuntary muscle tone and possible gaseous distention, it is a variable and relatively unreliable measurement.

A measurement less subject to variations in posture or tone of the musculature is the pelvic bicristal diameter. This represents the maximal distance between the external margins of the iliac crests, measured by calipers with the child in a recumbent position. Older children may be measured in erect position. The breadth of the pelvis usually reflects quite well the general stockiness of the child. Average values for different ages are recorded in Table 5.

WEIGHT

In any group of measurements, that of the body weight, because it sums up all the increments in size, is probably the best index of nutrition and growth. This is particularly true in infancy. In any period of life there are wide variations within normal limits. Careful clinical evaluation of the subject is necessary to avoid errors. The obese infant, although he weighs

TABLE 6.—WEIGHT OF AMERICAN GIRLS*

Age	Mean		Standard Deviation	
	Lb.	Kg.	Lb.	Kg.
3 months	13.0	5.9	1.5	0.7
6 months	17.0	7.7	1.8	0.8
9 months	19.7	8.9	2.1	1.0
1 year	21.9	9.9	2.5	1.1
1½ years	25.0	11.3	3.0	1.4
2 years	27.6	12.5	3.0	1.4
2½ years	30.1	13.6	3.6	1.6
3 years	32.5	14.7	3.9	1.8
3½ years	35.0	15.9	4.2	1.9
4 years	37.2	16.9	4.6	2.1
4½ years	40.0	18.1	5.2	2.4
5 years	42.3	19.2	5.8	2.6
6 years	48.3	21.9	7.6	3.4
7 years	54.5	24.7	8.9	4.0
8 years	61.9	28.1	10.5	4.8
9 years	69.6	31.6	12.9	5.8
10 years	78.1	35.4	14.7	6.7
11 years	88.4	40.1	17.0	7.7
12 years	100.4	45.5	18.8	8.5
13 years	110.5	50.1	18.7	8.5
14 years	120.1	54.5	18.6	8.4
15 years	126.6	57.4	18.4	8.3
16 years	130.5	59.2	18.2	8.2
17 years	133.5	60.5	18.1	8.2

*Modified from Simmons.[16]

more than a healthy one wisely fed, is certainly not in a better state of nutrition. Infants in whom edema is developing will show a gain which is quite misleading in the absence of frank edema. Such factors, and more could be listed, must be recognized in order to evaluate properly the meaning of an individual's weight.

During the first few days of the neonatal period some loss of weight is normal, usually less than 10 per cent of birth weight. This is accounted for by the initial loss of meconium and urine and by the inadequacy of the milk supply from the breast at this time. In some infants, particularly prematures, some of this loss may be due to disappearance of a "physiologic" edema during the first week. Birth weight is generally regained by

the tenth day. Thereafter, in health, a steady gain ensues. The mean birth weight is usually given as 7–7.5 lb. (3.4 kg.). During the first three months the average baby gains close to 2 lb. a month, or nearly 1 oz. a day, so that at 5 months he has doubled his birth weight. At 6 months of age the average gain is down to 1 lb. a month. Birth weight is tripled by the end of the first year and quadrupled by the end of the second year. During the

TABLE 7.—WEIGHT OF AMERICAN BOYS*

Age	Mean		Standard Deviation	
	Lb.	Kg.	Lb.	Kg.
3 months	14.3	6.5	1.5	0.7
6 months	18.7	8.5	1.8	0.8
9 months	21.7	9.8	2.2	1.0
1 year	23.8	10.8	2.5	1.1
1½ years	26.9	12.2	2.7	1.2
2 years	29.2	13.2	3.0	1.4
2½ years	31.5	14.3	3.3	1.5
3 years	33.5	15.2	3.6	1.6
3½ years	35.9	16.3	4.0	1.8
4 years	38.1	17.3	4.3	2.0
4½ years	40.5	18.4	4.6	2.1
5 years	42.8	19.4	5.0	2.3
6 years	48.2	21.9	5.8	2.6
7 years	54.2	24.6	7.0	3.2
8 years	61.0	27.7	8.8	4.0
9 years	68.4	31.0	10.8	4.9
10 years	76.8	34.8	12.9	5.9
11 years	85.6	38.8	16.2	7.3
12 years	95.2	43.2	19.0	8.6
13 years	105.7	47.9	21.0	9.5
14 years	119.1	54.0	22.2	10.1
15 years	132.3	60.0	21.4	9.7
16 years	141.9	64.4	20.3	9.2
17 years	147.6	66.9	19.6	8.9

*Modified from Simmons.[16]

second year the monthly increment is reduced to slightly more than ½ lb., the rate of gain steadily decreasing. As the child grows older the increase in weight is less regular, and it may remain stationary for a week or two at a time in healthy subjects during the second year and for even longer periods in older children. Generally speaking, after the age of 2 the annual increment in weight averages about 5 lb. until the ninth or tenth birthday (Tables 6 and 7), with the curve of weight increments showing a slow steady increase.

The time of onset of rapid gain in weight during adolescence corresponds closely in both sexes with the gain in height. The duration of the gain in weight, however, covers a longer span.[22] The adolescent accelera-

tion occurs earlier in girls than in boys, the most rapid spurt beginning in girls at 10–12 years, and in boys two years later. This rapid growth is greatest the year before menarche. It continues in girls until they are 20. After 20, gains are negligible in either sex.

A rough estimate of weight during preschool and early school years may be obtained by using the formula:

$$\text{age (in years)} \times 5 + 18 = \text{weight (in pounds)}$$

HEIGHT

Unlike weight, the annual increments in height continually diminish from birth to maturity except for a short period referred to as the adolescent spurt of growth. The average birth length is about 20 in.

TABLE 8*A*.—Stature of American Girls*

Age	Mean		Standard Deviation	
	In.	Cm.	In.	Cm.
Recumbent				
3 months	23.3	59.2	0.8	2.1
6 months	25.8	65.5	0.9	2.3
9 months	27.6	70.2	1.0	2.5
12 months	29.2	74.2	1.1	2.7
18 months	31.9	81.1	1.3	3.3
Standing				
18 months	31.5	80.0	1.2	3.1
2 years	33.9	86.1	1.3	3.2
2½ years	35.9	91.1	1.3	3.4
3 years	37.6	95.4	1.4	3.6
3½ years	39.2	99.5	1.5	3.7
4 years	40.7	103.3	1.5	3.9
4½ years	42.2	107.2	1.7	4.2
5 years	43.5	110.6	1.7	4.4
6 years	46.3	117.6	1.9	4.7
7 years	48.7	123.8	2.0	5.0
8 years	51.1	129.8	2.1	5.3
9 years	53.3	135.3	2.2	5.6
10 years	55.5	141.0	2.3	5.9
11 years	58.1	147.7	2.6	6.5
12 years	60.7	154.2	2.7	6.8
13 years	62.8	159.5	2.5	6.3
14 years	64.1	162.9	2.3	5.8
15 years	64.9	164.8	2.2	5.5
16 years	65.2	165.5	2.0	5.2
17 years	65.2	165.5	2.0	5.1

*Modified from Simmons.[18]

(50 cm.). By the end of the first year the infant has increased his birth length by about 50 per cent. He has doubled it by the age of 4 years. During the early school years the curve of height increments is nearly

flat and the average annual gain is 2 in. or a little better. By the thirteenth year the birth length has trebled.

In girls the adolescent acceleration of growth in length occurs from approximately 10 to 12 years, whereas for boys the acceleration is usually

TABLE 8B.—STATURE OF AMERICAN BOYS*

Age	Mean		Standard Deviation	
	In.	Cm.	In.	Cm.
Recumbent				
3 months	24.1	61.1	0.9	2.3
6 months	26.5	67.3	0.9	2.4
9 months	28.3	72.0	0.9	2.4
12 months	30.0	76.1	1.0	2.5
18 months	32.5	82.6	1.0	2.6
Standing				
18 months	32.2	81.9	1.1	2.7
2 years	34.4	87.4	1.1	2.9
2½ years	36.3	92.2	1.3	3.2
3 years	38.0	96.4	1.3	3.4
3½ years	39.4	100.2	1.4	3.6
4 years	40.9	104.0	1.5	3.8
4½ years	42.2	107.6	1.5	3.9
5 years	43.6	110.7	1.6	4.1
6 years	46.3	117.7	1.7	4.4
7 years	48.7	123.8	1.8	4.6
8 years	51.1	129.9	1.9	4.9
9 years	53.3	135.4	2.0	5.1
10 years	55.5	141.0	2.2	5.5
11 years	57.4	145.9	2.4	6.1
12 years	59.6	151.4	2.7	6.8
13 years	62.0	157.5	3.1	7.8
14 years	64.9	164.8	3.3	8.3
15 years	67.4	171.1	2.9	7.3
16 years	69.0	175.2	2.5	6.3
17 years	69.5	176.6	2.3	5.8

*Modified from Simmons.[16]

from 12 to 14 years. From 13 years in girls and 15 years in boys the rate of growth in stature rapidly decelerates. Growth ceases in girls at from 17 to 19 years but may continue in boys at a very slow rate beyond the twentieth birthday.[10] In each individual child the rapid spurt of growth is most pronounced during the earliest period of the acceleration. It is only when a cross-section of many children is considered that the curve is broadened.[22] Thus the individual grows at a much more rapid rate and for a relatively shorter time than a composite curve would indicate. The menarcheal relationships to the time of attainment of terminal height are the same as those described for weight. Of course, there is variation in the annual increments of stature among children of the same age. For any

TABLE 9A.—Weight Percentile Table: Boys (Birth to 18 Years)*
(Stuart and Meredith)

Age	Weight in Pounds 3%	10%	25%	50%	75%	Weight in Pounds 90%	97%
Birth	5¾	6¼	7	7½	8¼	9	10
1 mo.	7½	8½	9	10	10½	11½	13
2 mo.	9	10	10½	11½	12	13¼	14¾
3 mo.	10½	11	11¾	12½	13½	14½	16¼
4 mo.	11¾	12½	13¼	14	15	16¼	18
5 mo.	13	13¾	14¼	15	16½	17¾	19½
6 mo.	14	14¾	15½	16¾	18	19¼	20¾
7 mo.	15	15¾	16¾	18	19	20¾	22¼
8 mo.	15¾	16¾	17¾	19	20½	22	23½
9 mo.	16½	17¾	18¾	20	21½	23	24½
10 mo.	17¼	18¼	19½	20¾	22½	23¾	25¼
11 mo.	18	18¾	20¼	21½	23¼	24½	26¼
12 mo.	18½	19½	20¾	22¼	23¾	25½	27¼
13 mo.	19	20	21¼	22¾	24½	26	27¾
14 mo.	19½	20½	22	23¼	25	26½	28½
15 mo.	19¾	21	22½	23¾	25½	27¼	29½
16 mo.	20¼	21½	23	24¼	26	27¾	30¼
17 mo.	20¾	21¾	23½	24¾	26½	28½	31
18 mo.	21	22¼	23¾	25¼	27	29	31½
19 mo.	21½	22¾	24¼	25¾	27½	29½	32¼
20 mo.	22	23¼	24¾	26	28	30	33
21 mo.	22¼	23½	25	26½	28½	30½	33½
22 mo.	22½	24	25½	26¾	28¾	31	34
23 mo.	23	24¼	26	27¼	29¼	31½	34½
24 mo.	23¼	24¾	26¼	27¾	29¾	32	35
2½ yr.	25¼	26½	28½	30	32¼	34½	37
3 yr.	27	28¾	30¼	32¼	34½	36¾	39¼
3½ yr.	28½	30½	32¼	34¼	36¾	39	41½
4 yr.	30	32	34	36½	39	41½	44¼
4½ yr.	31½	33¾	35¾	38½	41½	44	47½
5 yr.	34	36	38½	41½	45¼	48¼	51¾
5½ yr.	36¼	38¾	42	45½	49¼	53	56½
6 yr.	38½	41	44½	48¼	52	56½	61
6½ yr.	40¾	43½	47	51¼	55½	60½	65½
7 yr.	43	45¾	49¾	54	58¾	64½	70
7½ yr.	45½	48½	52½	57	62	68¾	74¾
8 yr.	48	51¼	55½	60	65½	73	79½
8½ yr.	50¼	53¾	58¼	63	69	77	84½
9 yr.	52½	56¼	61	66	72¼	81	89¾
9½ yr.	54¾	58¾	63¾	69	76	85½	95
10 yr.	56¾	61	66¼	72	79½	90	100
10½ yr.	59¼	63¾	69	74¾	83½	94½	105¾
11 yr.	61¾	66¼	71½	77½	87¼	99¼	111¾
11½ yr.	64½	69¼	74½	81	91½	104½	118
12 yr.	67¼	72	77½	84½	96	109½	124¼
12½ yr.	69½	74½	80½	88¾	102	116½	131
13 yr.	72	77	83¾	93	108	123¼	138
13½ yr.	76	82¼	89½	100¼	115½	130	144¼
14 yr.	79¾	87¼	95½	107½	123	137	150½
14½ yr.	85½	93¼	102	114	129	142½	156
15 yr.	91¼	99½	108¼	120	135	147¾	161½
15½ yr.	97½	105¼	113½	125	139¾	153½	166
16 yr.	103½	111	118¾	129¾	144½	157¼	170½
16½ yr.	107	114¼	121½	133	148	161	173
17 yr.	110½	117½	124½	136¼	151½	164½	175½
17½ yr.	111¾	118¾	125¾	137½	153½	166¾	177¼
18 yr.	113	120	127	139	155¾	169	179

*Adapted by the Health Department, Milwaukee, Wis., from anthropometric charts based on original data of H. C. Stuart and H. V. Meredith and prepared for use in Children's Medical Center, Boston.

TABLE 9B.—Weight Percentile Table: Girls (Birth to 18 Years)*
(Stuart and Meredith)

Age	Weight in Pounds 3%	10%	25%	50%	75%	90%	Weight in Pounds 97%
Birth	5¾	6¼	7	7½	8	8½	9½
1 mo.	7	8	8½	9¾	10¼	11	11¾
2 mo.	8¼	9½	10¼	11	11¾	12½	13½
3 mo.	9½	10¾	11½	12¼	13	13¾	14¾
4 mo.	10¾	12	12¾	13¾	14½	15½	16½
5 mo.	11¾	13	13¾	14¾	16	17	18¼
6 mo.	12¾	14	14¾	15¾	17¼	18½	19¾
7 mo.	13½	15	16	17	18½	20	21¼
8 mo.	14¼	15¾	16¾	18	19½	21¼	22½
9 mo.	14¾	16¼	17½	18¾	20¼	22	23½
10 mo.	15½	17	18¼	19¾	21¼	23	24¾
11 mo.	16	17½	19	20½	22	23¾	25¾
12 mo.	16½	18	19½	21	22½	24½	26½
13 mo.	17	18½	20¼	21¾	23¼	25¼	27½
14 mo.	17½	19	20¾	22¼	23¾	25¾	28
15 mo.	18	19½	21¼	22¾	24½	26½	28¾
16 mo.	18½	20	21¾	23¼	25	27	29½
17 mo.	18¾	20½	22¼	23¾	25½	27½	30
18 mo.	19¼	21	22½	24¼	26	28	30¾
19 mo.	19½	21½	23	25	26½	28¾	31¼
20 mo.	20	21¾	23½	25½	27	29¼	32
21 mo.	20¼	22¼	23¾	25¾	27½	29¾	32½
22 mo.	20¾	22¾	24¼	26¼	28	30½	33
23 mo.	21¼	23	24¾	26¾	28½	31	33¾
2 yr.	21½	23½	25¼	27	29¼	31¾	34½
2½ yr.	23½	25½	27½	29½	32	35½	38¼
3 yr.	25½	27½	29½	31¾	34½	37½	41¾
3½ yr.	27½	29½	31½	34	37	40½	45¼
4 yr.	29¼	31¼	33½	36¼	39½	43½	48¼
4½ yr.	30¾	33	35¼	38½	42	46¾	51
5 yr.	33	35½	38	41	44½	48¾	52¼
5½ yr.	35	38	40¾	44	47¼	51¼	55½
6 yr.	37¼	39½	43	46½	50¼	54¼	58¾
6½ yr.	39¾	42¼	45½	49½	53¼	57¾	63
7 yr.	41¼	44½	48	52¼	56¼	61¼	67¼
7½ yr.	43¼	46½	50½	55¼	59¾	65½	73
8 yr.	45¼	48½	53	58	63¼	70	79
8½ yr.	47¼	50½	55½	61	67	74½	84½
9 yr.	49	52½	58	63¾	70½	79	90
9½ yr.	51¼	55	60½	67	74¾	84½	96
10 yr.	53¼	57	62¾	70¼	79	89¾	102
10½ yr.	55½	60	66½	74½	84	95	107½
11 yr.	58	62½	70	78¾	89	100½	113
11½ yr.	60¾	66	74	83¼	94	106	120¼
12 yr.	63½	69½	78	87½	98¾	111½	127¾
12½ yr.	68	74¾	83¾	93½	105	118	135
13 yr.	72¼	80	89½	99	111	124½	142¼
13½ yr.	77¾	85½	94½	103¾	115½	129	146½
14 yr.	83	91	99¾	108½	119¾	133¼	150¾
14½ yr.	86	94¼	102½	111	121¾	135¾	153
15 yr.	89	97½	105	113½	124	138	155¼
15½ yr.	90½	99¼	106¾	115¼	125½	139½	156½
16 yr.	91¾	101	108½	117	127¼	141	157¾
16½ yr.	92¾	102	109½	118	128½	142¼	158½
17 yr.	94	102¾	110½	119	129½	143¼	159½
17½ yr.	94¼	103¼	110¾	119½	130¼	144	160
18 yr.	94½	103½	111¼	120	130¾	144½	160¾

*Adapted by the Health Department, Milwaukee, Wis., from anthropometric charts based on original data of H. C. Stuart and H. V. Meredith and prepared for use in Children's Medical Center, Boston.

TABLE 9C.—HEIGHT PERCENTILE TABLE: BOYS (BIRTH TO 18 YEARS)*
(Stuart and Meredith)

	LENGTH IN INCHES					LENGTH IN INCHES	
AGE	3%	10%	25%	50%	75%	90%	97%
Birth	18¼	19	19½	20	20½	21	21½
1 mo.	19¾	20¼	20¾	21¼	22	22¼	22¾
2 mo.	21	21½	22	22½	23	23½	24
3 mo.	22½	22¾	24¼	23¾	24¼	24¾	25
4 mo.	23½	23¾	24¼	24¾	25¼	25¾	26
5 mo.	24¼	24½	25	25½	26	26½	27
6 mo.	24¾	25¼	25¾	26	26¾	27¼	27¾
7 mo.	25½	26	26¼	26¾	27¼	28	28½
8 mo.	26	26½	27	27½	28	28¾	29¼
9 mo.	26½	27	27½	28	28¾	29¼	30
10 mo.	27	27½	28	28½	29¼	29¾	30½
11 mo.	27½	28	28½	29	29¾	30¼	31
12 mo.	28	28½	29	29½	30¼	30¾	31½
13 mo.	28½	29	29½	30	30¾	31¼	32
14 mo.	29	29½	30	30½	31¼	31¾	32½
15 mo.	29¼	29¾	30¼	31	31½	32	33
16 mo.	29¾	30¼	30¾	31½	32	32½	33½
17 mo.	30¼	30½	31¼	31¾	32½	33	34
18 mo.	30½	31	31½	32¼	33	33½	34¼
19 mo.	31	31½	32	32¾	33¼	34	35¼
20 mo.	31¼	31¾	32½	33	33¾	34½	35½
21 mo.	31½	32	32¾	33¼	34	34¾	36
22 mo.	32	32½	33	33¾	34½	35	36½
23 mo.	32¼	32¾	33½	34	34¾	35½	36¾
24 mo.	32½	33	33¾	34½	35¼	36	37¼
2½ yr.	34¼	34¾	35½	36¼	37	38	39¼
3 yr.	35¾	36¼	37	38	38¾	39½	40½
3½ yr.	37	37¾	38½	39¼	40¼	41	42
4 yr.	38½	39	39¾	40¾	42	42¾	43½
4½ yr.	39½	40¼	41	42	43¼	44¼	45
5 yr.	40¼	41¼	42¼	43¼	44½	45½	46½
5½ yr.	41½	42½	43¾	45	46¼	47¼	48
6 yr.	42¾	43¾	45	46¼	47½	48½	49¾
6½ yr.	43¾	45	46	47½	49	50	51
7 yr.	45	46	47½	49	50¼	51½	52½
7½ yr.	46	47¼	48½	50	51½	52¾	53¾
8 yr.	47	48½	49¾	51¼	52¾	54	55¼
8½ yr.	48	49½	50¾	52¼	54	55	56¼
9 yr.	49	50½	51¾	53¼	55	56	57¼
9½ yr.	49¾	51½	52¾	54¼	56	57	58¼
10 yr.	50¾	52¼	53¾	55¼	56¾	58	59¼
10½ yr.	51½	53¼	54½	56	57¾	59	60
11 yr.	52½	54	55¼	56¾	58¾	59¾	60¾
11½ yr.	53½	55	56¼	57¾	59½	61	62¼
12 yr.	54½	56	57¼	59	60½	62¼	63¾
12½ yr.	55¼	57	58	60	62	63½	65¼
13 yr.	56	57¾	59	61	63¼	65	66¾
13½ yr.	56¾	58¾	60¼	62½	64¾	66½	68¼
14 yr.	57½	60	61½	64	66¼	68	69¾
14½ yr.	58¾	61	62¾	65	67¼	68¾	70¾
15 yr.	59¾	62	64	66	68	69½	71½
15½ yr.	60¾	63	64¾	66¾	68¾	70¼	72¼
16 yr.	61½	64	65¾	67¾	69½	70¾	73
16½ yr.	62	64½	66¼	68	69¾	71	73¼
17 yr.	62½	65¼	66¾	68½	70	71½	73½
17½ yr.	62¾	65¼	67	68½	70¼	71½	73¾
18 yr.	62¾	65½	67	68¾	70½	71¾	74

*Adapted by the Health Department, Milwaukee, Wis., from anthropometric charts based on original data of H. C. Stuart and H. V. Meredith and prepared for use in Children's Medical Center, Boston, Mass.

TABLE 9D.—Height Percentile Table: Girls (Birth to 18 Years)*
(Stuart and Meredith)

Age	Length in Inches 3%	10%	25%	50%	75%	90%	Length in Inches 97%
Birth	18½	18¾	19¼	19¾	20	20½	21
1 mo.	19¾	20¼	20½	21	21½	22	22½
2 mo.	21	21½	21¾	22¼	23	23¼	23¾
3 mo.	22	22½	22¾	23½	24	24¼	24¾
4 mo.	22¾	23¼	23¾	24¼	24¾	25¼	25¾
5 mo.	23½	24	24½	25	25½	26	26½
6 mo.	24	24½	25	25¾	26¼	26¾	27
7 mo.	24½	25¼	25¾	26¼	27	27½	27¾
8 mo.	25¼	25¾	26¼	27	27½	28	28½
9 mo.	25¾	26½	27	27½	28¼	28¾	29¼
10 mo.	26¼	27	27½	28	28¾	29¼	29¾
11 mo.	26¾	27¼	28	28½	29¼	29¾	30½
12 mo.	27	27¾	28½	29¼	30	30¼	31
13 mo.	27½	28¼	29	29½	30¼	30¾	31½
14 mo.	28	28½	29½	30	30¾	31¼	32
15 mo.	28¼	29	29¾	30½	31¼	31¾	32½
16 mo.	28¾	29½	30¼	31	31¾	32¼	33
17 mo.	29	29¾	30¾	31¼	32¼	32¾	33½
18 mo.	29½	30¼	31	31¾	32½	33¼	34
19 mo.	30	30½	31½	32¼	33	33¾	34½
20 mo.	30¼	31	32	32½	33½	34¼	35
21 mo.	30½	31¼	32¼	33	33¾	34¾	35½
22 mo.	31	31¾	32¾	33¼	34¼	35¼	36
23 mo.	31¼	32	33	33¾	34½	35½	36¼
24 mo.	31½	32¼	33¼	34	35	35¾	36¾
2½ yr.	33¼	34	35¼	36	37	38	39
3 yr.	34¾	35½	36¾	37¾	38½	39¾	40¾
3½ yr.	36¼	37	38	39¼	40¼	41½	42½
4 yr.	37½	38½	39½	40½	41½	43	44¼
4½ yr.	38½	39¾	40¾	42	43	44¾	45¾
5 yr.	40	41	42	43	44¼	45½	46¾
5½ yr.	41¼	42½	43½	44½	45¾	46¾	48
6 yr.	42½	43½	44½	45½	47	48	49½
6½ yr.	43¾	44¾	45¾	47	48¼	49½	50¾
7 yr.	45	46	47	48	49½	50¾	52
7½ yr.	46	47	48	49¼	50¾	52	53
8 yr.	47	48	49	50½	51¾	53	54
8½ yr.	47¾	49	50	51½	53	54	55¼
9 yr.	48¾	50	51	52¼	54	55¼	56½
9½ yr.	49½	51	52	53½	55	56½	57¾
10 yr.	50¼	51¾	53	54½	56	57½	58¾
10½ yr.	51¼	53	54	55¾	57½	59	60½
11 yr.	52	54	55¼	57	58¾	60½	62
11½ yr.	53¼	55	56¼	58¼	60¼	61¾	63½
12 yr.	54¼	56	57½	59¾	61½	63¼	64¾
12½ yr.	55½	57½	58¾	60¾	62½	64	65½
13 yr.	56½	58¾	60	61¾	63¾	65	66¼
13½ yr.	57½	59½	60¾	62½	64	65¼	66¾
14 yr.	58¼	60¼	61½	62¾	64½	65¾	67¼
14½ yr.	58¾	60¾	61¾	63	64¾	66	67½
15 yr.	59	61	62	63½	65	66¼	67½
15½ yr.	59¼	61¼	62¼	63¾	65	66½	67¾
16 yr.	59½	61½	62½	64	65¼	66½	67¾
16½ yr.	59½	61½	62½	64	65½	66½	67¾
17 yr.	59½	61½	62½	64	65½	66¾	67¾
17½ yr.	59½	61½	62½	64	65½	66¾	67¾
18 yr.	59½	61½	62½	64	65½	66¾	67¾

*Adapted by the Health Department, Milwaukee, Wis., from anthropometric charts based on original data of H. C. Stuart and H. V. Meredith and prepared for use in Children's Health Center, Boston, Mass.

given year one child's gain in height may be very small and still be normal for him, even though others of his age are becoming taller. Apparent growth retardation is most significant in the stages when growth should be accelerated. For instance, during infancy failure to grow in stature should be regarded with suspicion even in the absence of obvious disease (Tables 8*A* and 8*B*). It is of interest to note that a child's probable adult stature may be estimated, given adequate environmental conditions, by doubling the measurement attained at the age of 2 years.

A rough estimation of the expected height for given age may be obtained from the formula:

$$\text{age (in years)} \times 2 + 32 = \text{height (in inches)}$$

This is applicable only from the fourth to the eleventh year.

By the correlation of the height-age and weight-age data, a number of tables have been constructed which present mean weight for sex-age-height groups. An example is the Baldwin-Wood Tables;[2] a table can be so constructed that, given the age, sex and height of a child, the expected weight may be ascertained. This expected weight is the average for a large group of school children. If the child's actual weight is lower than the tabular weight by 6 per cent or more, the child is to be considered underweight. Several objections have been raised to the use of such tables in the appraisal of physical status. (1) There is a difference of opinion concerning the amount a given child may deviate from the mean figures before he should be considered abnormally over- or underweight for his age, sex, etc. (2) Unless deviations from the usual physique are excessive, they are apt to be overlooked. (3) Furthermore, such tables fail to present a graphic picture of the mean against which the individual's progress may be compared. The mean itself may be criticized as an undesirable standard because it is based on a child population that includes different levels, many of which are not optimal. Such tables do provide, nevertheless, a convenient standard and are frequently used.

Table 9 gives data for weight and height in percentiles, based on anthropometric charts (see Figs. 4*C* and 4*D*), against which a child's development may be observed. Weight is recorded to the nearest ounce and body length or height to the nearest ¼ in. The weight or height percentile tables for sex and age to the nearest month or half-year are consulted and the percentile group nearest the measurement recorded, adding + or − as indicated. If the measurement lies between two percentile

groups, both are indicated (e.g., 3–10). Weight measurements for a child usually fall in the same percentile group at succeeding ages or change only gradually from period to period. Height and weight often differ in their actual percentile positions, but tend to maintain the same general relationships from period to period. Eighty per cent of the weight measurements of children at a given age would be expected to fall between the 10th and 90th percentiles. Allowance must, of course, be made for the adolescent spurt in girls between 10 and 14 years and in boys between 11 and 16. Children with weight and height measurements which *(a)* fall in different percentile groups, *(b)* shift percentile groups subsequently or *(c)* fall near to or outside the 3d and 97th percentile should be reviewed for growth failure.

HEIGHT-WEIGHT CURVES

The presentation of norms in terms of curves has a decided advantage, providing a running account of the individual's measurements plotted against the pattern of growth of a large group of his own age. A child growing normally tends to maintain his relative position (percentile level) with respect to his age group. Growth trend as compared with that of other children is so represented that deviations may become apparent earlier than otherwise.

Jackson and Kelly[8] published charts containing both the height-age and weight-age curves on the same sheet for each sex (Figs. 4*A* and 4*B*). Their construction is based either on a mean curve and a standard deviation or on a percentile basis. Curves are presented for infancy, for the preschool child (first six years) and for children from 5 to 18 years. From the points plotted on the curve it is possible to determine a child's body build by obtaining his height-age and weight-age and relating the two. The points plotted on the height-age curve correspond to the age and height of the subject at the time of the examination. The points plotted on the weight-age curve correspond similarly.

Once the measurements are plotted, one looks at a picture of growth with the intermediate numerical steps dispensed with once and for all. Patterns of growth of the individual are compared with curves of the chart: levels of growth attained by the individual are examined in relation to the levels of the different percentiles of the chart. The weight-age curve is compared with the height-age curve to determine the subject's build and nutritional status. Any marked deviation from the curves of

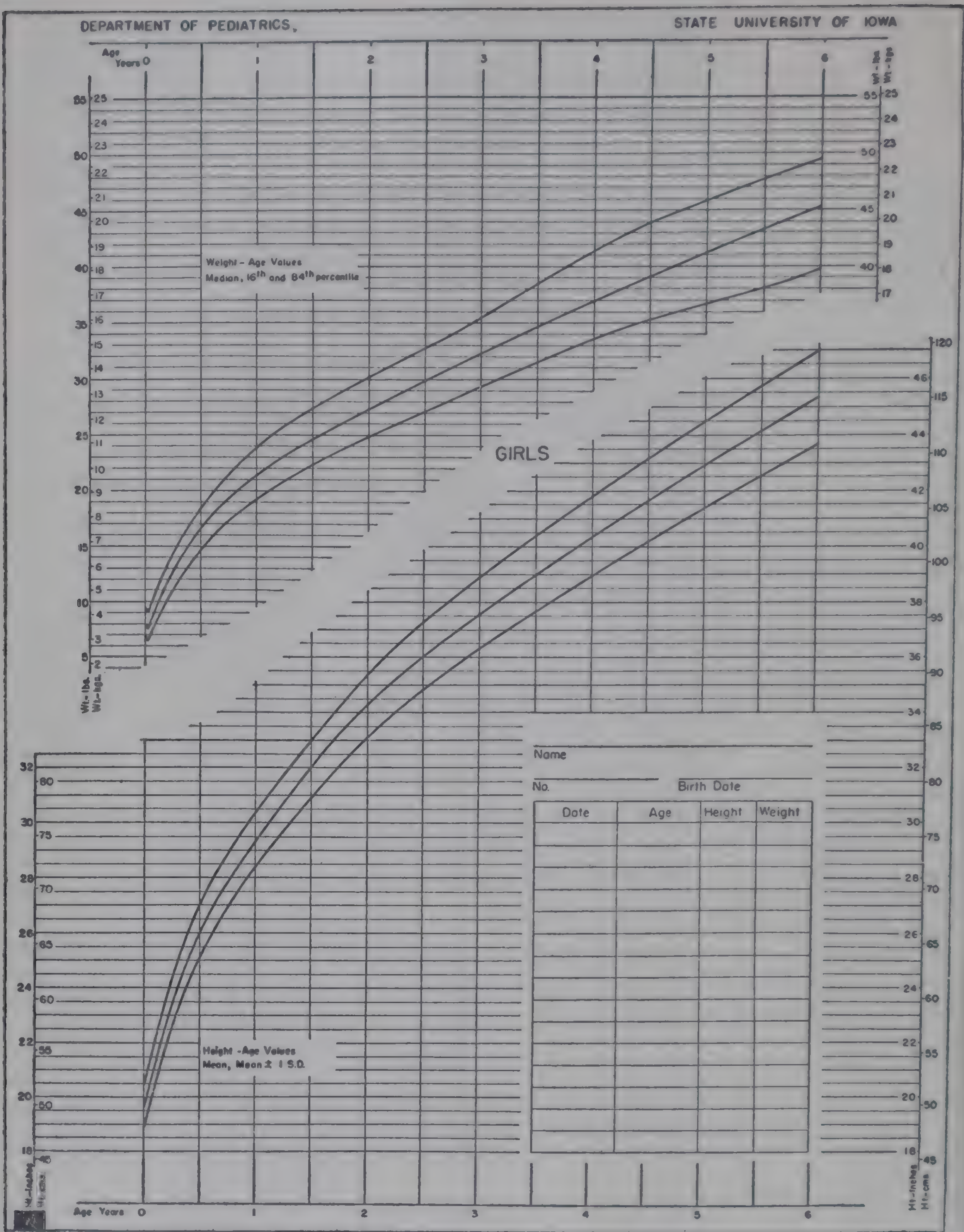


FIG. 4*A*.—Growth chart for girls; see also Figure 4*B*. Upper curve is used for weight-age values, the lower one for height-age values. (Figs. 4*A*-4*B* from Jackson, R. L., and Kelly, H. G.: J. Pediat. 27:215, 1945. These and charts for boys are obtainable from Department of Publications, East Hall, S.U.I., Iowa City, Ia., for $1.00 for each pad of 100 charts.)

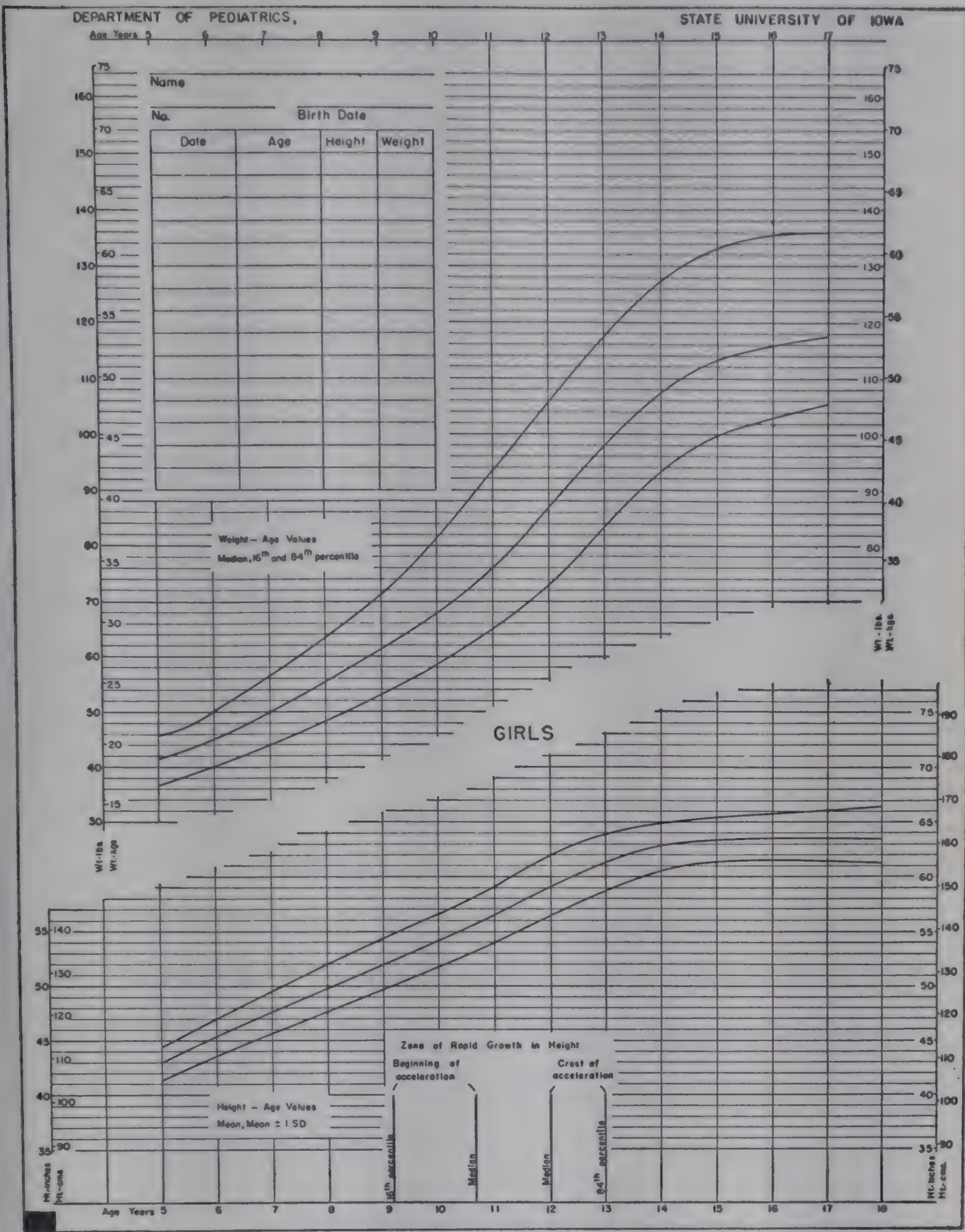


FIG. 4B.—Growth chart for girls; see also Figure 4A.

INFANT GIRLS

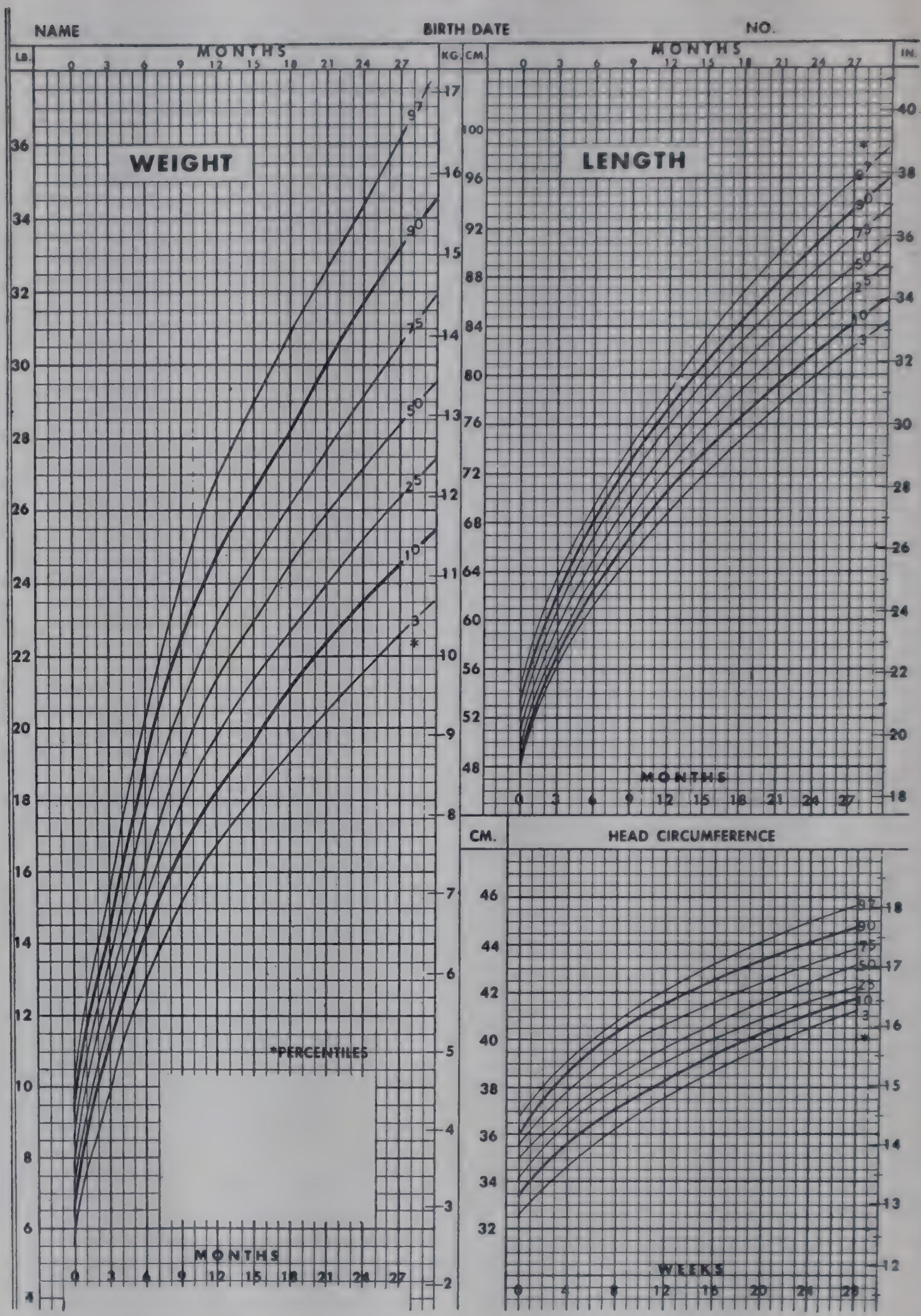


FIG. 4C.—Percentile chart for measurements of infant girls. (Courtesy of Harold C. Stuart; reproduced by permission of Children's Medical Center, Boston, from charts made available to physicians by Mead Johnson & Company, Evansville, Ind.)

GIRLS AGED 2–14

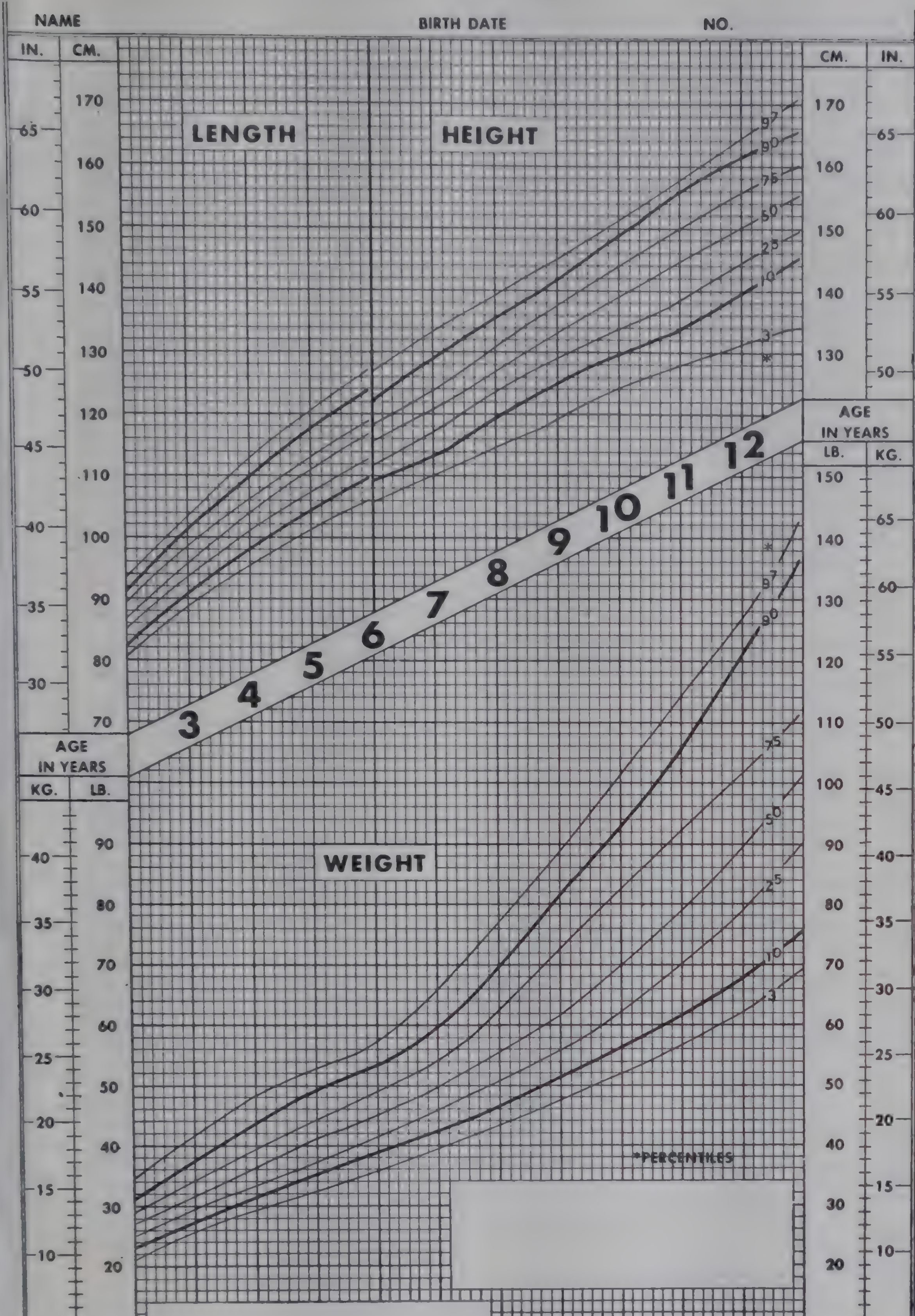


FIG. 4*D*.—Percentile chart for measurements of girls aged 2-14. (Courtesy of Harold C. Stuart; reproduced by permission of Children's Medical Center, Boston, from charts made available to physicians by Mead Johnson & Company, Evansville, Ind.)

the chart must be interpreted in the light of the medical and social history of the child and the results of physical examination.

On each chart is a set of three curves for height and for weight. The middle curve gives the average to be expected. The outside curves represent points on the scale that are one deviation above and one deviation below the average for height. For weight these curves represent the 84th

TABLE 10.—Expected Increments in Weight and Height*

Age	Weight, Lb.		Height, In.	
0-1 mo.	1.4		1.5	
1-3 mo.	3.4		2.4	
3-6 mo.	3.9		2.5	
6-9 mo.	3.0		1.8	
9-12 mo.	2.2		1.6	
12-18 mo.	3.1		2.6	
18-24 mo.	2.7		2.2	
24-30 mo.	2.3		1.9	
30-36 mo.	2.1		1.7	
36-42 mo.	2.3		1.5	
42-48 mo.	2.1		1.4	
48-54 mo.	2.4		1.4	
54-60 mo.	2.2		1.3	
60-66 mo.	2.5		1.4	
66-72 mo.	2.6		1.3	
	Boys	Girls	Boys	Girls
6-7 yr.	4.9	4.6	2.4	2.3
7-8 yr.	5.2	4.9	2.2	2.2
8-9 yr.	5.5	5.6	2.2	2.2
9-10 yr.	5.9	6.1	2.0	2.1
10-11 yr.	5.5	7.6	2.0	2.3
11-12 yr.	6.5	9.9	2.0	2.5
12-13 yr.	9.0	11.3	2.2	2.6
13-14 yr.	12.0	9.5	3.6	2.0
14-15 yr.	11.3	5.0	2.3	1.0
15-16 yr.	9.8	4.0	2.0	0.8
16-17 yr.	7.0	2.6	1.5	0.3

*Data represent averages from several sources.

and 16th percentiles, respectively. Among healthy children approximately 75 per cent will fall within the range of the two outer curves. The standards set by the median curve on each chart are considered by Jackson and Kelly to approach the optimum for general pediatric practice. (The children used to compile the data on which these charts are based were "favored by environment.")

In the final analysis of the growth of the child the expected rate of gain is of greater value than any single measurement. This information can be obtained from the tables already presented and is readily available from Table 10, although this is only an expected increment for a child

who is of average size and state of development. For example, the average gain in height for boys during the 14th year is 3.6 in. This is an average for early-, medium- and late-maturing boys as well as for large, medium and small boys. Some boys will make this large increment (3.6 in.) in the 13th year, some in the 15th year, and some will not make so large an increment in their year of greatest linear growth.

Harold C. Stuart and his associates in the Department of Maternal and Child Health, Harvard School of Public Health, have constructed anthropometric charts using percentiles rather than standard deviations. The percentile method of comparing one child with his peers, or of following his growth for months and years, is somewhat more flexible than the standard deviation method and is more readily understood. The Stuart charts are constructed to permit the recording of length, weight and head circumferences of infant boys or girls and of length and weight of both sexes to the thirteenth year. Only the charts for infant girls and for girls 2–13 are reproduced (Figs. 4*C* and 4*D*).

Figure 4*C* provides for infant girls standards of reference for body weight and recumbent length by month from birth to 28 months and for head circumference by week from birth to 28 weeks. Similarly, Figure 4*D* provides for girls standards of reference for body weight and recumbent length between ages 2 and 6 years and for weight and standing height from 6 to 13 years. They are based on repeated measurements at selected ages of groups of more than 100 white infants and more than 100 white girls of North European ancestry living under normal conditions of health and home life in Boston.

The distribution of the measurements obtained from the subjects at each age is expressed in percentiles, each percentile giving a value which represents a particular position in the normal range of occurrences. The number of the percentile refers to the position which a measurement of the given value would hold in any typical series of 100 infants or children. Thus, the 10th percentile gives the value for the tenth in any hundred; i.e., nine subjects of the same sex and age would be expected to be smaller in the measurement under consideration and 90 would be expected to be larger than the figure given. Similarly, the 90th percentile would indicate that 89 subjects might be expected to be smaller than the figure given and 10 would be larger. The 50th percentile represents the median or mid-position in the customary range. Measurements below the 3d and above the 97th percentile represent unusual but not necessarily abnormal findings.

Recognition of the position within or outside of the range held by the child with respect to each measurement recorded calls attention to the relative size and build of the individual at the time. More importantly, comparisons of percentile positions held by these measurements at repeated periodic examinations indicate adherence to or possibly significant deviation from previous percentile positions. In normal circumstances, one expects a child to maintain a similar position from age to age, i.e., on or near one percentile line or between the same two lines. Occasional sharp deviations or gradual but continuing shifts from one percentile position to another call for further investigation as to their causes.

THE WETZEL GRID

As a means of objectively assessing the physical condition of children, Wetzel [26–29] prepared his grid (Fig. 5), a chart based on the generally accepted principles that:

"1. Healthy progress prefers development along a channel of given body type on an age schedule or timetable specific for the subject and with preservation of that subject's natural physique.

"2. Each child should be considered his own standard of comparison." The grid is so constructed that it is possible to determine quantitative ratings on such attributes as physique, developmental level, basal metabolism and caloric needs from stature, weight, sex and age data. Figure 6 is a breakdown chart showing the grid's structure.

In the appraisal of physical condition by this technic there are two major considerations:

1. Evaluation of physical status, involving the study, measurement and interpretation of

   a) Physique or body build
   b) Developmental level (physical)
   c) Nutritional grade

2. Evaluation of physical progress or study of the relations between sequential physical states as defined by

   a) Channel course
   b) Auxodromic progress

In conditions of good growth and development a child will maintain his physique by progressing channelwise at the rate of 12 levels per year. Through this definite tendency to keep to the same channel at such a rate that he progresses one level per month it is possible to decide whether a

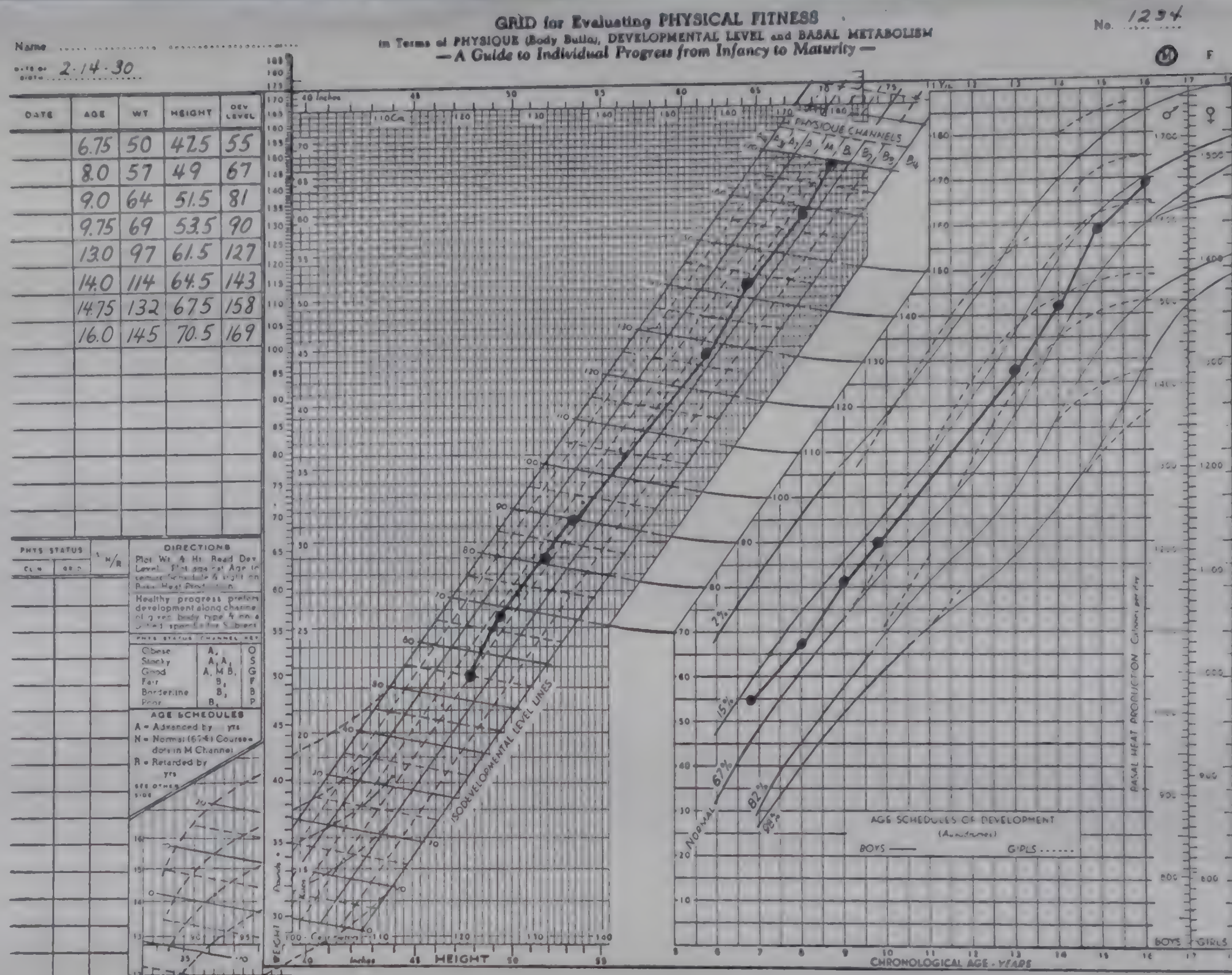


Fig. 5.—The Wetzel grid; see text and Figure 6 for explanation of its use. The record here is for a normal boy plotted over a period of nearly 10 years and showing satisfactory progress. (Reproduced by permission of N. C. Wetzel.)

child is in the proper channel. However, a shift of less than one-half channel per 10 levels is permissible provided the trend is not persistent. About 60 or 70 per cent of children fall within the three center channels. The optimal nutritional slope is along the path of the given channel into which the child falls. The developmental age is determined by reading the age at which the 67 per cent norm intersects a given developmental level (auxodrome).

Wetzel has also prepared a baby grid in which the grid technic may be applied to infants from birth to 3 years.[30] It contains the channel system,

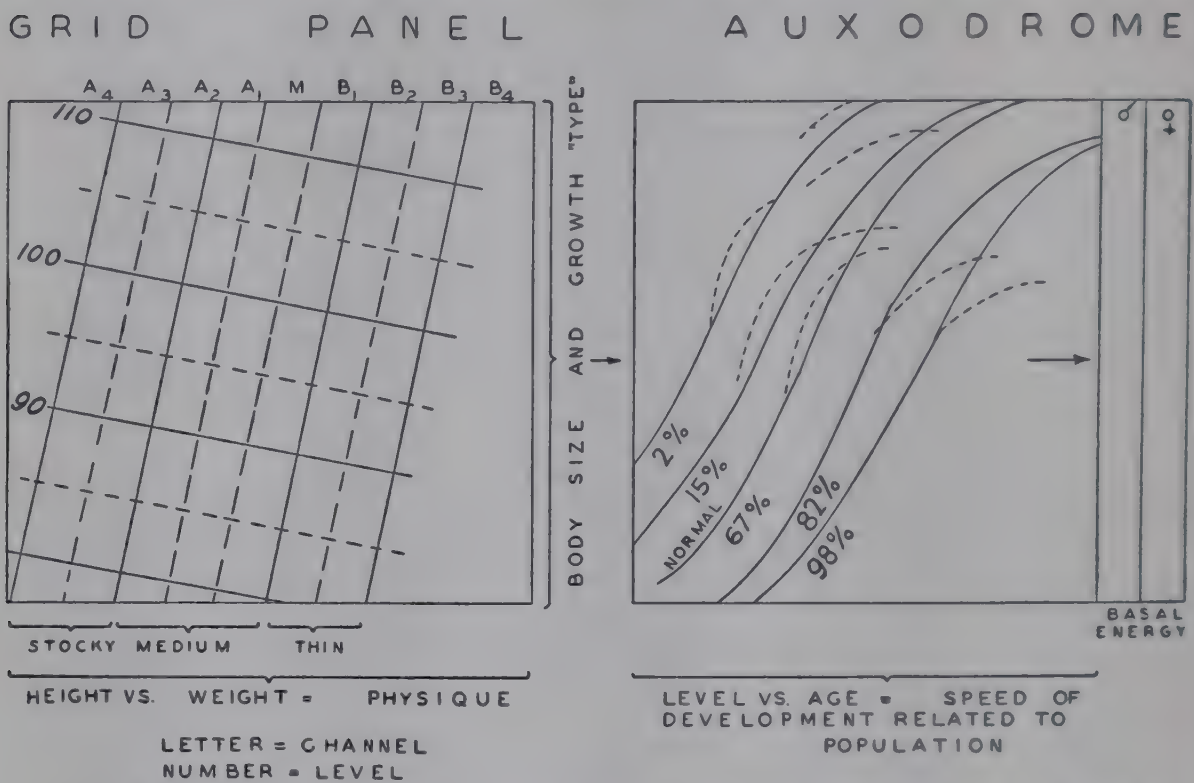


Fig. 6.—Breakdown of the Wetzel grid to show its interpretation and method of use. In the auxodrome, broken lines are for girls, unbroken lines for boys.

auxodrome, energy relations panel and two subsidiary panels permitting graphing of head and chest circumferences. In addition, events of motor and mental development and tooth eruption appear on the channel system at the developmental level where they may be expected to occur. Tables giving values for body surface, blood volume and diet composition are arranged by steps of 10 levels. In this age period, as in more advanced periods, development proceeds along a channel at such a rate that the baby's auxodrome keeps within two to three levels of running parallel to the standard. Because infants are naturally more chubby than the older children, early growth proceeds along channels A_{12}–A_5, gradually turning

toward the main line A_3–M–B_3. This is reached at slightly over a year by average babies.

If a longitudinal study of a child has been maintained for even a brief period, deviations from the expected "channel course" and the "auxodrome progress" quickly become apparent. Therefore, although a child may remain within the limits of average variation according to many methods used to measure development, some abnormality may easily be suspected if there is such a deviation from the expected course on a Wetzel grid. It is stated that hidden or incipient disease becomes apparent at an earlier time. Undernutrition and overnutrition become obvious sooner. Each child has his or her own individual growth pattern, and when this pattern is disturbed the physician becomes aware that some abnormality is present. Use of the Wetzel grid has been advocated because such changes become more quickly noticeable than by use of the older height-weight-age charts. We would take some exception to this view.

Wetzel's grid is at times criticized as being too complex for general application. However, the computations of its assembly need not be considered in its use, so that practical employment of the grid technic is relatively simple. A further criticism is that developmental age is given as an adequate substitute for skeletal age in the assessment of maturation. As already mentioned, the developmental age is a function of the developmental level which represents almost exclusively an age-size rating. Thus, an obese child would be considered much farther advanced toward maturity than a child of medium or slender build equally developed in all other respects on this basis. Wetzel's reply* to this criticism is that many obese children do fall on or near the 67 and 82 per cent auxodromes and that accordingly they are not advanced even though obese. He also states that age advancement should be considered independent of physique. Finally, we must realize that no treatment of height and weight data has resulted in a timetable by which maturity level can be accurately assessed, since they themselves are variables at maturity.

MNEMONICS

Anyone who has occasion to appraise the growth and development of children realizes the need for some system of remembering approximate heights and weights of various ages. One such aid in general use has been the statement that at 2 years of age the child is probably one-half as tall

*Personal communication.

as he will be at maturity. Another is that at 3 years the child is 3 ft. tall, or at 4 years is 40 in. tall; or at 3½ years the average child weighs 35 lb. and at 7 years weighs seven times his birth weight.

Weech has added several mnemonics to those already in use and tested

TABLE 11.—WEIGHT PREDICTION FROM AGE (3–12 MONTHS)*
Formula: weight = age + 11

Age, Mo.	Weight, Lb.					
	Mitchell-Nelson		Holt-McIntosh		Grand Av.	Predicted by Formula
	Boys	Girls	Boys	Girls		
3	12.6	12.4	14.3	13.0	13.1	14
6	16.7	16.0	18.7	17.0	17.1	17
9	20.0	19.2	21.7	19.7	20.2	20
12	22.2	21.5	23.8	21.9	22.4	23

*Tables 11-15 from Weech, A.A.: Sign posts on highway of growth, A.M.A. Am. J. Dis. Child., September, 1954.

TABLE 12.—WEIGHT AS FUNCTION OF AGE

Age, Yr.	Average (or Median) Values, Lb.				Grand Av., Lb.	Predicted by Formula, Lb.*	
	Mitchell-Nelson		Holt-McIntosh			(6 x age) + 12	(7 x age) + 5
	Boys	Girls	Boys	Girls			
4	36.4	36.2	38.1	37.2	37.0	36	
5	40.5	40.5					
5	42.8	41.4	42.8	42.3	41.9	42	
6	48.3	46.5	48.2	48.3	47.8	48	
7	54.1	52.2	54.2	54.5	53.8	54	
8	60.1	58.1	61.0	61.9	60.3	60	61
9	66.0	63.8	68.4	69.6	67.0		68
10	71.9	70.3	76.8	78.1	74.3		75
11	77.6	78.8	85.6	88.4	82.6		82
12	84.4	87.6	95.2	100.4	91.9		89
13	93.0	99.1	105.7	110.5	102.1		96
14	107.6	108.4	119.1	120.1	113.8		103

*Weight from age 4-8 years is approximately six times the age plus 12. From 8-12 years, the formula should be seven times age plus 5. Here both formulas apply to age 8 years, yielding substantially the same figure.

TABLE 13.—MNEMONICS FORMULAS FOR PREDICTING WEIGHT
Av. growth in weight—girls and boys
(Mitchell-Nelson; Holt-McIntosh)

Age	Weight, Lb.
Birth	7.35
3–12 mo.	Age (mo.) + 11
30 mo.	30
3.5 yr.	35
4–8 yr.	(6 x age) + 12
8–12 yr.	(7 x age) + 5

them against tables of height and weight in the Holt and McIntosh and Mitchell-Nelson textbooks. Tables 11–15 contain Weech's mnemonic formulas and illustrate how values obtained by these formulas compare with those in the aforementioned texts.

TABLE 14.—Height as Function of Age

Formula: height = (2½ × age) + 30

Age, Yr.	Av. (or Median) Values, In.				Grand Av., In.	Predicted by Formula, In.
	Mitchell-Nelson		Holt-McIntosh			
	Boys	Girls	Boys	Girls		
2	34.4	34.1	34.4	33.9	34.2	35.0
3	37.9	37.7	38.0	37.6	37.8	37.5
4	39.7	40.6	40.9	40.7	40.5	40.0
5	42.8	42.9				
5	43.8	43.2	43.6	43.5	43.4	42.5
6	46.3	45.6	46.3	46.3	46.1	45.0
7	48.9	48.1	48.7	48.7	48.6	47.5
8	51.2	50.4	51.1	51.1	51.0	50.0
9	53.3	52.3	53.3	53.3	53.1	52.5
10	55.2	54.6	55.2	55.5	55.1	55.0
11	56.8	57.0	57.4	58.1	57.3	57.5
12	58.9	59.8	59.6	60.7	59.8	60.0
13	61.0	61.8	62.0	62.8	61.9	62.5
14	64.0	62.8	64.9	64.1	64.0	65.0

TABLE 15.—Weight as Function of Height (2-12 Years)

Formula: $\text{weight} = 48 + \left(\frac{\text{height}}{2} - 23\right) \cdot \left(\frac{\text{height}}{10}\right)$

Age, Yr.	Grand Av. for Boys and Girls (Mitchell-Nelson; Holt-McIntosh)		Predicted by Formula, Lb.
	Height, In.	Weight, Lb.	
2	34.2	27.9	27.8
3	37.8	32.5	32.5
4	40.5	37.0	36.9
5	43.5	41.9	42.6
6	46.1	47.8	48.2
7	48.6	53.8	54.3
8	51.0	60.3	60.8
9	53.1	67.0	66.9
10	55.1	74.3	73.1
11	57.3	82.6	80.4
12	59.8	91.9	89.3
13	61.9	102.1	97.2
14	64.0	113.8	105.6

GROWTH AS A WHOLE

Olson and Hughes,[12,13] of the University of Michigan Laboratory School, have devised a table to show the longitudinal development of the child as a whole. On one table are plotted measurements of various mental and physical attributes. These workers feel that by using such a method they have the "life history of any given child over a significant age span" and also a table which takes into consideration the interrelationship of many factors of development. The unit of description is age and each

measure is converted into an age value. Using this principle, one can plot height, weight, number of erupted teeth, strength of grip, carpal age, mental age (Kuhlmann-Binet), educational age (Stanford), social age (Doll) and many others against a common scale. A manual has been compiled to assist in the translation of the various measurements into age units (reprinted from Olson and Hughes[13]).

Data so far acquired by the use of this table have shown a remarkable

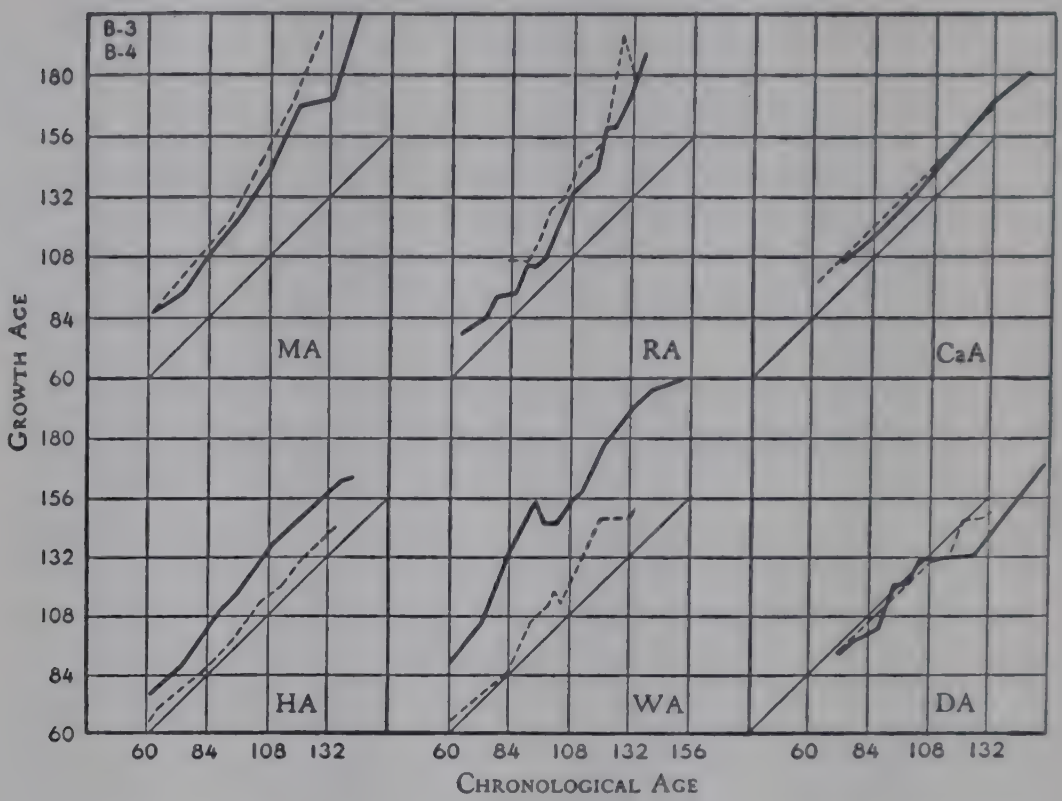


Fig. 7.—Curves showing similarity of growth patterns of brothers born 33 months apart, plotted on a chart similar to that in Figure 8. Course of growth is shown for mental age *(MA)*, reading age *(RA)*, carpal ossification *(CaA)*, height *(HA)*, weight *(WA)* and dental development *(DA)*. (From Olson, W. C., and Hughes, B. O., in Barker, R. G., *et al.* (ed.): *Child Behavior and Development* [New York: McGraw-Hill Book Company, Inc., 1943].)

correlation of all of the measures used; i.e., in most instances there is a marked homogeneity of all measures of physical and mental growth.* Studies of siblings have shown a high degree of similarity in the pattern of growth (Fig. 7). Finally, the diverse data for each subject are averaged

*In a study of gifted children (those with an I.Q. of 140 and over) Terman and Oden[33] found that both physical and mental development were above the average and that this superiority continued into adult life. They believe that favorable environment alone cannot explain these observations.

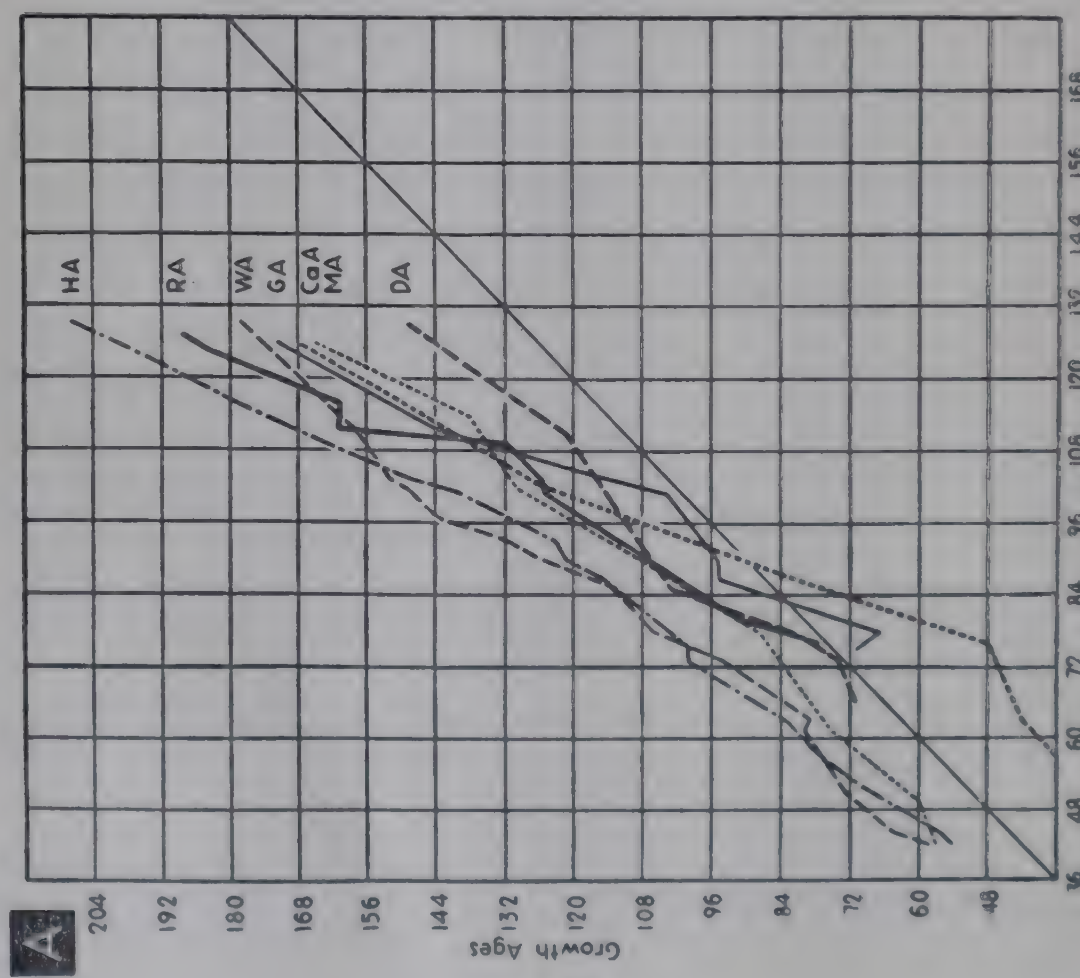
from all of the age levels and this is plotted against chronological age. This average for the individual has been termed the "organismic age" by Olson and Hughes. They state that the liberty taken in averaging these diverse data is based on the hypothesis that all data are samples of structures and functions of the organism and that individuals having different patterns may be "organismically" equal. "Organismic age" divided by chronological age equals the "organismic quotient" which can be used to determine, in general, the status of any child. Figure 8 shows the data and the table of one subject studied who exhibited an accelerated total growth and of another subject with slow growth.

In general, when a wide scattering of the several elements which are measured is maintained throughout several successively plotted points it can be postulated that the inherited characteristics have been variable. For example, when the parents of a child are of widely different physical builds there may be a wide range in the different physical measurements of the child. The lines of height, weight and carpal age may fall far apart on the table. Disease and emotional stress are quickly reflected by a lowering of all or some of the elements measured. The authors cite one example in which death of the mother resulted in a drop in weight and "reading age" over a period of six months until a suitable adjustment was accomplished.

Olson and Hughes have applied statistical tests to many similar systems of curves for individual children and have concluded that in all growth there is an underlying unity. They also believe that achievement in school is a function of the total growth of the child, and they doubt that school achievement is primarily a matter of curriculum and method, provided environment is suitable. When the "organismic age" for a child is calculated for successive life ages and the points are plotted and connected, much stability and predictability of trend are revealed. As a matter of fact, each child tends to grow in a more steady and orderly manner when the average values for "organismic age" are used than when a single attribute is plotted. This type of evidence suggests some "central maturational tempo or release of energy at a steady rate, with a tendency toward a balancing of the various aspects of the whole."[12]

THE FELS COMPOSITE SHEET

The Fels method makes use of variability units to describe growth in many factors relative to time.[19] The mean and standard deviations of each


A
Growth Ages
Chronological Ages
HA
RA
WA
GA
CaA
MA
DA
A
I
B
II
M
C
III

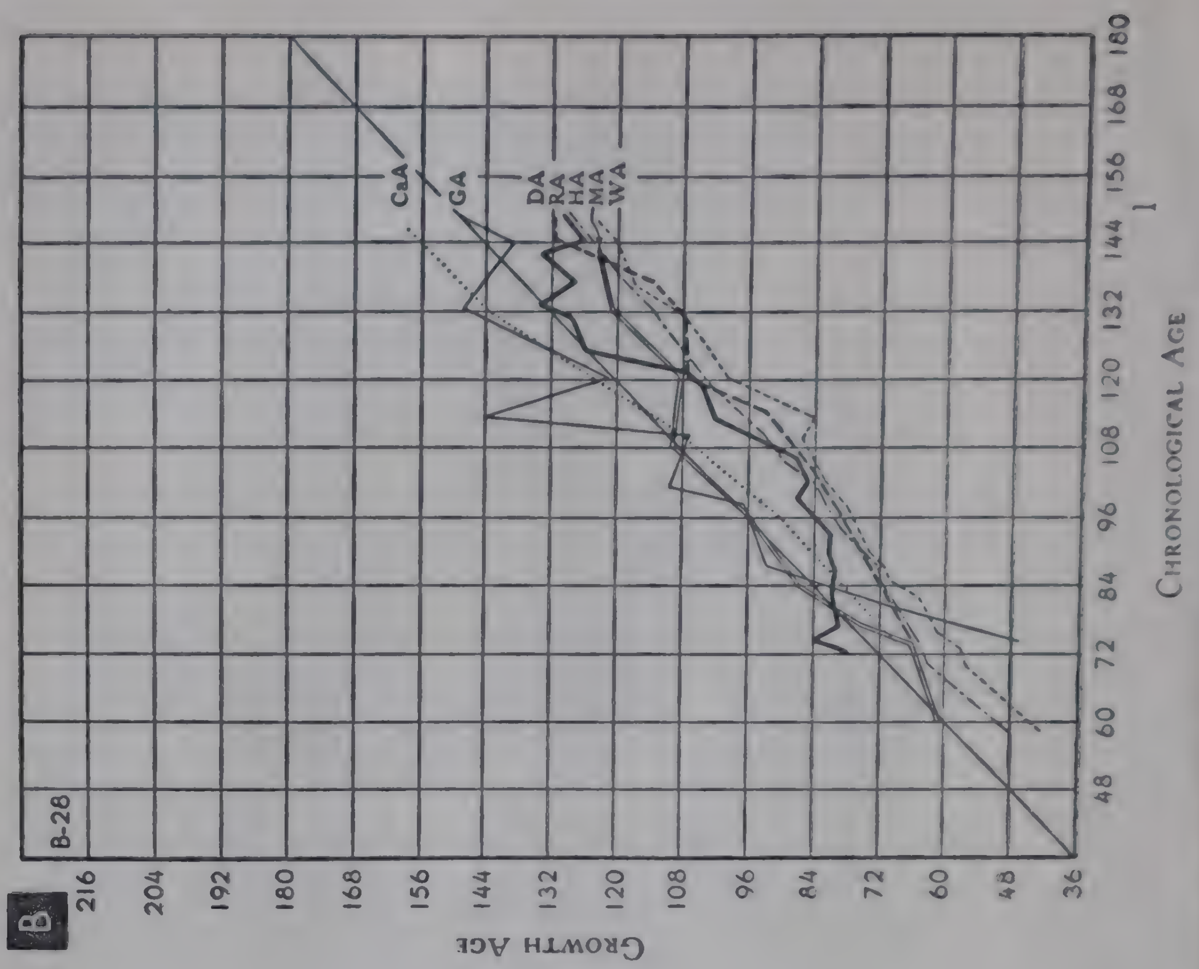

B
B-28
Growth Age
Chronological Age
CaA
GA
DA
RA
HA
MA
WA

FIG. 8.—The Olson-Hughes growth chart. Various physical and mental measurements plotted, *A*, for a girl who is above average, and *B*, for a boy slightly below average. On the abscissa, *A*, *B* and *C* represent advancing degrees of breast development; pubic hair development is indicated as *I* present, *II* pigmented, and *III* pigmented and curly; *M* indicates menarche. The straight, unbroken diagonal line represents average course for all measurements. For both children the homogeneity of all the factors measured is clearly apparent. The table below, for chart *A*, shows the functions measured at the chronological age of 108 months. The figures in the right-hand column are obtained from a manual (see text) giving age equivalents, and these are plotted on the ordinate opposite the chronological age on the abscissa. (From W. C. Olson and B. O. Hughes.)

Function Measured	Raw Score	Abbreviation	Age Equivalent
Height	60.4 in.	HA	160
Reading	28 items correct	RA	130
Weight	96 lb.	WA	156
Strength of grip	19.7 kg.	GA	130
Ossification of hand and wrist	x-ray	CaA	135
Mental capacity	Tests passed	MA	134
Dental eruption	16 permanent teeth	DA	119
Organismic age		OA	138
Variability		AD	11.7
Chronological age		CA	108

measure (height, weight, ossification, dietary adequacy, biochemical values, performance tests, etc.) are first calculated by age and sex. Thereafter, any measurement obtained can be described or plotted in terms of variability rather than in terms of the absolute value of the units used in originally collecting the data. With this method, the average is always arbi-

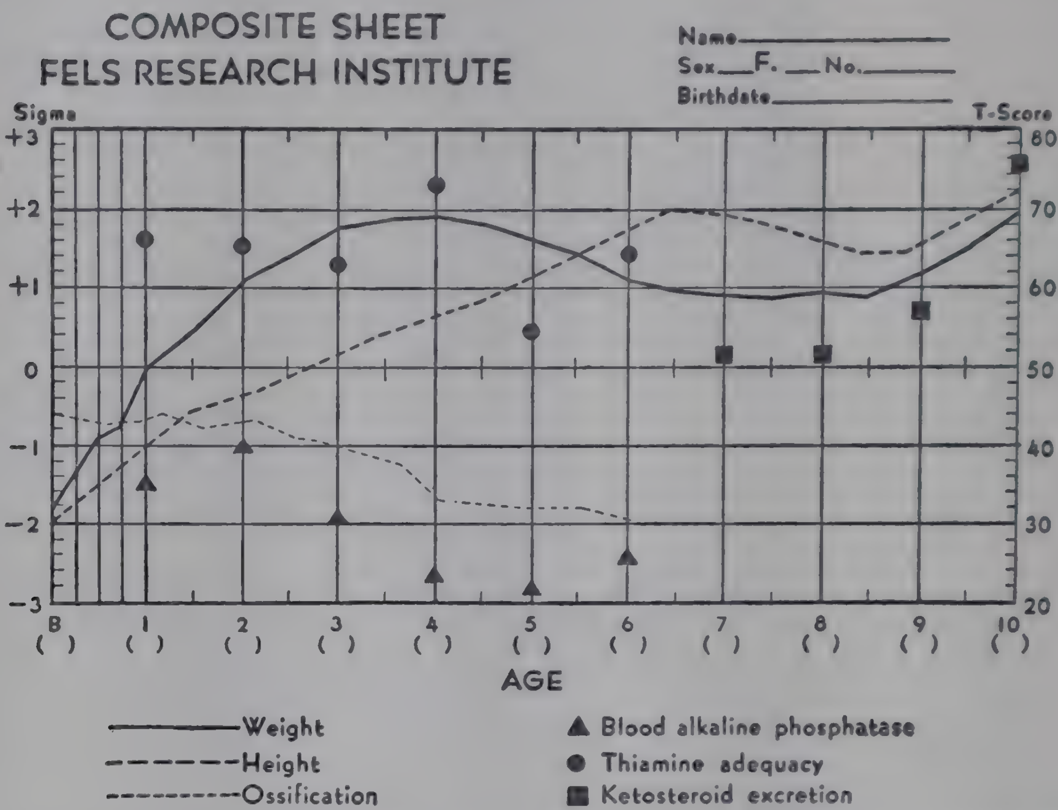


FIG. 9.—The Fels composite sheet, showing growth of a girl from birth to 10 years. The abscissa is in units of chronological age. The left ordinate is expressed in units of 1 or more standard deviations (sigma) of expected values for a specific age on the abscissa; the right ordinate, in units of the T-score in which 50 represents the expected mean. At birth the child was 2 sigmas below the mean for height and weight, but by 4 years was above the mean in weight and near the mean in height. From this record one can conclude that at birth she was small but well proportioned and at 4 was of stocky body build. Various other factors are indicated according to the key below the chart. (Reproduced by permission of L. W. Sontag.)

trarily placed at 50 and the scale is then laid out in terms of variability units. One standard deviation above the average or mean is always 60; two standard deviations above are 70, etc. A single standard deviation below would then be 40. The score for any measure is called the T-score, average T-score being 50. In the plotting of this material, age in years (or months) represents the abscissa and the ordinates are in units of T-score and sigma (units of standard deviation). The advantage of the standard deviation

method is that many measures which do not show an age trend but which do reveal individual differences can be plotted to show relative status in the group. By plotting a series of determinations, profiles at various ages on a vertical axis will be obtained (Fig. 9).

Examples of many other tables and curves could be presented, many of which have considerable merit. However, those described seem to represent fairly the basic principles that have been used in an effort to answer that most important question, "Is this child growing normally?" Again it should be emphasized that an adequate clinical history is vital for an understanding and proper interpretation of somatic and mental growth. Deviations from the expected average are without meaning unless such factors as illness, emotional trauma, nutrition and genetics are all properly evaluated.

In the following outline are summarized the advantages of using tables and graphs as well as the more obvious disadvantages.

ADVANTAGES

1. They may give a very general indication of a subject's health when other more detailed methods are not available, as in schools where the medical personnel is limited.
2. Charts and graphs are useful in studying the effects of fairly well controlled factors on two or more different groups of children. They may be of aid in "field studies" of physical growth.
3. They may be used to bring together in an easily presentable form various data, as in the Olson-Hughes chart.
4. The attempt to secure and interpret simple measurements improves clinical judgment when wisely used.
5. They may bring to one's attention certain abnormalities or peculiar characteristics in an individual child. We are well aware that the first indication of disease may be failure to gain weight, loss of weight or failure to grow in stature.
6. A graphic presentation of some point is often better understood by parents than volumes of explanation. Showing a mother that her child is following a "normal" curve of growth and development is often more convincing than reassuring words.
7. The development of the various methods, and the accumulation of data for construction of the tables, etc., have added immeasurably to our understanding of the growth and development of children.

LIMITATIONS AND FAULTS

1. Tables and charts cannot and should not be used as substitutes for an adequate history-taking and physical examination.
2. When an individual child falls within the "normal" range a false sense of security may be established. As a single example, a child may be of normal height and weight and yet suffer from a severe vitamin deficiency.
3. Many standards now in use cannot be applied to different racial groups or to groups from widely divergent geographic areas. Separate standards applicable to the subjects undergoing examination should be used.
4. Dependence on tables and charts may cause lazy thinking in terms of "points" or "graphs" instead of the consideration of the child as an individual.
5. Tables and curves do not indicate nor define optimal growth and development.
6. In a few instances the complexity or impracticality of the method may defeat its purpose for common clinical use.

POSTURE

In the past 20 years our ideas concerning correct posture have changed greatly. The physical educators and hygienists were once dogmatic about it, and rigid standards were established. We have since become aware that no one posture can be termed the "correct" one. We now recognize that it is a functional attribute and that posture depends on the age, the occupation, the physique and the health of the individual. Furthermore, the general consensus seems to be that so-called "poor" posture is seldom detrimental unless, of course, it is the result of some pathologic condition. Good posture, as opposed to that which is both functionally and esthetically bad, is certainly desirable. It looks well and therefore promotes self-respect. It may also aid in physical efficiency and general well-being. To define "good posture" is probably an impossibility in view of our present knowledge; at least, no one definition can be said to hold for all individuals.

Posture changes with age.[1, 12] There are many factors involved, but at least two important ones are the variations in the curves of the vertebral column and the shifting center of gravity. At birth the entire presacral vertebral column is extremely flexible and no particular curve may be

described as truly characteristic since it depends entirely on the position of the infant. At 3 or 4 months, when the infant begins to hold up his head an anterior convexity of the cervical portion appears. Nevertheless, the cervical vertebrae remain freely movable and at no time become fixed in any one position. By the time an upright posture is assumed the forward lumbar convexity develops, but it is not far advanced for several years. An important contribution to this curve is the fact that the anterior portion of the last three lumbar vertebrae become increasingly thicker than the posterior portions. Even the intervertebral disks in this region develop similar inequalities. The tilting of the pelvis and the pull of the psoas muscles in an erect position tend to maintain the lumbar curvature. In the thoracic region, growth of the vertebral bodies is the reverse of that of the lumbar area; i.e., the posterior portions of the bodies are thicker than the anterior portions, resulting in a forward concavity. The sacral curve is present from birth but contributes little to posture except in maintaining the position and relationships of the pelvis. The only two relatively fixed curves of the vertebral column involved in the posture of the child are the lumbar and the thoracic, and even these can be said to show great flexibility throughout the entire growing period.

Since the proportions of head, trunk and extremities vary so greatly with growth, it is natural that the center of gravity of the body change with age.† The location of this point is relative not only to posture but to all functions in which balance is involved. In the newborn in an erect position, the center is near the level of the xiphoid, and throughout early childhood it remains above the umbilicus. At 5-6 years it is just below the umbilicus and is below the crest of the ilium by 13 years. With increasing age there is also an increasing ability to maintain balance because of muscle co-ordination and strength. Although posture may be said to have some basis in nutrition and exercise, it is strongly influenced by the unfolding design of growth of skeletal, muscular and neuromuscular mechanisms.

During the first two to three years after an erect posture is assumed, the feet are relatively flat, there is a tendency to inward bowing of the legs from knee to ankle, some lordosis is apparent which varies a great deal from child to child, and the abdomen is prominent. In the early school period, the shoulders are "rounded," and this is little influenced by exercise. A "military" posture of head high, shoulders back and chest

†Center of gravity may be determined by the formula $y = 0.557 \cdot X + 1.4$ cm., where y equals distance of the center above the soles and X equals height in centimeters.[14]

equal with the plane of the abdomen comes with adolescence. In general, a satisfactory posture may be said to exist at this time if a straight line passes from in front of the ear through the shoulder and the greater trochanter to the anterior part of the longitudinal arch of the foot. Such a posture distributes the weight equally to the balls of the feet and permits an erect yet comfortable standing position. Forcing such an attitude on a child, however, is hardly to be advised. Posture, to a degree, reflects strength and health, and these factors are the more basic conditions which should receive our consideration.

To the clinician a peculiarity of posture may be viewed as a sign of simple fatigue or of some more definite organic or mental disturbance. It must be emphasized that both the general and the detailed forms of the body are highly variable. We cannot assume that there is a single correct posture any more than we can assume that there is a single correct height or weight. The old idea of admonishing school children to "stand straight" or "sit straight" in the interest of better posture often confuses cause and effect. A child typically adopts that posture which keeps the parts of his body in proper balance. Frequent action and change of activity in school are excellent preventives of faulty posture.

One interesting condition related to posture in children is orthostatic or postural albuminuria. This apparently benign condition is usually limited to children with rather pronounced lordosis, but may appear in its absence. Most cases have been reported to clear up completely with puberty, and no known kidney abnormalities are associated with it. It has been variously reported to occur in 5–20 per cent of children at one time or another. An impairment of venous blood supply to the kidneys while the child is in an upright position has been suggested as an etiologic factor.[7]

GROWTH AND DEVELOPMENT OF LEGS AND FEET

The legs and feet grow more rapidly than the trunk during childhood. Both legs and feet respond to some degree to external factors which may be operative before or after birth. Bowed tibiae have been attributed to abnormal and restricted positioning in utero. Many varieties of clubfoot are seen at birth, some of which seem rather clearly to be due to abnormal positioning or pressures in utero. Imbalance of muscle groups and muscle pull will produce grotesque anomalies of foot or leg, as in arthrogryposis.

After birth the legs and feet continue to respond in their growth to

the stresses incident to position and function. The obvious gross aberrations from normal come within the province of the orthopedist. However, there are certain variations of or from normal with which the pediatrician should be familiar. Some simulate pathologic growth and development but need no specific treatment, whereas others may require simple exercises or some modification of shoes to encourage more normal stance and gait. Herzmark[31] believes that the usual smooth and often soft surfaces on which children usually learn to walk favor the assumption and continuation of an unphysiologic stance and gait and walking habits that may become a source of disability later in life. Specifically he believes that children should learn to walk on knobby or pebbled surfaces as do primitive peoples. The smooth surfaces of the playpen and carpeted floors cause the infant to separate his feet, turn them outward. He "throws the weight on the longitudinal arches, everts the heels, and thrusts the head of the astragali medially." It is difficult in many instances to decide whether actual abnormal growth and development are taking place, and consequently whether treatment is needed (Fig. 10, *A*).

Flatfoot.—The infant just learning to walk may seem to exhibit the principal signs of flatfoot—flattening of the longitudinal arch, abduction of the forefoot and eversion of the heel (Fig. 10, *B*). Some infants have a definite longitudinal arch, well formed before walking. Others, who seem to have little or no arch before walking, later prove to have a normal foot.

Nordenfelt[32] believes that a child should not be urged to walk until he is able to pull himself to his feet because too early standing and assisted walking strain the arches and may stretch the plantar aponeurosis, thus contributing to flatfoot. He advised barefootedness as much as possible during the preschool period. Nordenfelt's recommended foot covering is a knit upper with a chamois or other soft leather sole, similar to the stocking-shoes worn indoors by many persons. It should always be large enough to avoid restricting the foot or ankle in any way.

If the signs of flatfoot are minimal but persist after walking is started, the foot can be assisted toward normal development by an ⅛ in. elevation of the sole on the medial side and by use of the Thomas heel (Fig. 11). The wedging is usually carried along the medial side of the sole as far as the metatarsal heads. Much is gained also from simple manipulations by the mother. These consist of gentle turning of the forefoot medially and inversion of the heel. Well into the second year the child can be

taught to aid foot growth by standing pigeon-toed and rising in such a manner as to throw his weight on the outer edges of the forefeet. Should it be apparent that the foot deformity threatens to become worse or is not yielding to these simple measures, the child should be seen by an orthopedist.

Because a child has a well developed longitudinal arch, it does not follow that he has a normal or strong foot. Nor is a flat foot necessarily a weak or functionally poor foot. Compere[33] stated that a flat foot may be functionally a good foot and stand hard usage and described the hereditary type of flatfoot which may need no corrective treatment if it is flexible and the heel is not everted or inverted.

A primarily normal foot with good longitudinal and transverse arches, good flexibility and muscle control may be injured by jumping from a height. The actual injury may lead to abnormal stance because of pain and soreness and start a train of events leading to abnormal feet and gait. Also, the child who has been ill for several weeks may suffer foot strain (muscles and ligaments) if ambulation is resumed too rapidly. Here a tendency to pronation and eversion may strain the medial collateral ligaments of the knees and result in genu valgum. Mild instances of such weak pronated feet are aided by use of the Thomas heel and $\frac{1}{8}$ or $\frac{3}{16}$ in. wedges to raise the medial edge of the foot. Such modifications may be used for several years with benefit to foot growth.

Pigeon-toed feet.—These are not always strong, comfortable feet despite the fact that children, like cars, seem to run best when they toe in slightly. If the toeing-in is acute, the child trips and "falls over his own feet." Pigeon-toe may result from any factor or combination of factors which leads to rotation of the foot inward from normal position. If the whole leg is rotated inward or if the tibia undergoes internal torsion or twisting during growth, the foot will be rotated inward, resulting in pigeon-toes. A third condition which will produce pigeon-toe is varus deformity—medial angulation—of the forefoot (Fig. 12).

Orthopedic consultation is needed to manage all but the most minor cases of varus forefoot or pigeon-toes. Because in some instances the feet are normal and the deformity is actually one of curvature and inward rotation of the leg, accurate diagnosis and continued supervision of corrective measures are essential. The severest forms of varus forefoot require the application of casts followed by manipulation, and ortho-

Fig. 10 *(above)*.—*A,* normal feet and legs of 13 month old child just beginning to walk, the stance giving the appearance of genu valgum and some pronation. Observation of the child in action indicated good sturdy legs and feet. *B,* simple flatfoot with resulting genu valgum. Whole foot rotates outward, the longitudinal arch disappears, heads of the astragali thrust medially and the heel is everted.

Fig. 11 *(below left)*.—Thomas heel, elevated medially and with medial side prolonged to support the longitudinal arch and counter medial thrust of the astragalus.

Fig. 12 *(below right)*.—Pigeon-toed foot. Ankle and knee of a boy of 13 months are in normal relationship, but forefoot deviates medially and is rotated. This foot seems far worse than it really is, and the boy could walk with support

Fig. 13.—*Top,* lift on outer half of sole to correct mild toeing-in. The lift, ⅛ or 3/16 in. thick at the sole edge, tapers to almost nothing at the midline. It is glued and often sewn on. *Center,* Hack toe-out shoes; these are essentially switched shoes to provide abducting pressure to correct uncomplicated metatarsus varus. *Bottom.* Sable corrective shoes, wedged all along the lateral side to tilt the foot and apply abducting counterpressure to the forefoot.

Fig. 14.—Physiologic bowing of legs. *Left,* with rather pronounced genu varum in boy of 18 months. Feet are in fairly good alinement, though there is some tibial torsion-external rotation. The boy walked and ran with ease but "waddled." In three years there was full recovery without treatment. *Right,* thickening of medial cortex of tibiae due to stress. (From Holt, J. F., *et al.*: J.A.M.A. 154:390-394, Jan. 30, 1954.)

pedic advice should be sought early. On the other hand, prevention of a tendency to tibial torsion due to faulty position during sleep or play is within the province of the mother acting on the advice of the physician.

If by the time the child begins to walk it is apparent that there is a tendency to pigeon-toe, fairly simple measures may reverse the tendency. A wedge on the outer side of the sole of the shoe to lift the forefoot (Fig. 13, *A*), and sometimes on both forefoot and heel, may counter the shift of weight to the outer side of the foot and improve alinement. Another device is the shoe designed to prevent simple toeing-in beyond the normal physiologic pattern (Fig. 13, *B* and *C*); these should be prescribed in orthopedic consultation. Some infants and runabout children are aided by use of the Denis-Browne splint during sleeping. The splint consists of plates fastened to the soles of the shoes and connected to a cross-bar. The key part is a rachet and wing-nut combination which permits rotation of the foot. Internal rotation should be corrected very gradually by wearing of the splint during sleep for three to six months while growth brings about correction of the deformity.

Physiologic bowing of the legs.—This is a normal variation of growth, is self-correcting and, though often mistaken for rickets, shows no x-ray evidence of rickets (Fig. 14). The bowing is more apparent than real and reaches its maximum during the second year. Obeying the laws of stress, the medial cortex of both tibias is greatly thickened. There is a tendency to abnormal medial thrust of the feet and some pronation simulating flatfoot. If the latter is pronounced, treatment should be that for simple flatfoot.

Children's shoes.—Children customarily begin wearing shoes before 1 year of age and wear them most of the year. Shoes protect against weather and most ordinary trauma to the feet. They may also be a source of deforming stresses, or they may be so constructed as to be a corrective agent by applying pressure or tilt to a foot which is growing in an unfavorable direction. Physicians should be prepared to answer parents' questions about the type of shoe (high or low; soft sole or hard) and should be alert to inspect worn shoes for evidence of abnormal foot development.

Shoes must be long enough and wide enough in the forepart to allow complete freedom from constriction: remember that the forefoot broadens somewhat with each step. High-top shoes are not necessary to support a child's ankles, but they are desirable because it is difficult to fit the heel

snugly enough to prevent slipping without at the same time making the shoe too tight.

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5

The Premature Child

From the standpoint of death rate, prematurity represents the single most important problem of the neonatal period, accounting for approximately half the total number of deaths during this time. Although many different factors are involved, it is recognized that the smaller the infant, the less are his chances of survival. The problems of prematurity must be approached from two aspects: the prevention of premature births, and extension of our knowledge of the premature infant so that improvement in his care will be possible. An obvious part of the necessary knowledge pertains to growth and development. In the following paragraphs the physical growth and development of the premature infant are summarized and the various physiologic differences between the premature and the normal full term infant are outlined. The discussion is necessarily brief but should orient the reader regarding expected patterns of growth and development in the premature infant.

Definition.—The definition of prematurity according to the U.S. Bureau of the Census and the Children's Bureau is "the termination of pregnancy in the period from the beginning of the twenty-eighth to the end of the thirty-seventh week of gestation." The earlier time denotes the lower limit at which successful maintenance of extrauterine existence may be expected. The later limit has been selected because the date of the beginning of pregnancy cannot be estimated accurately within two or three weeks.

Because estimation of the duration of pregnancy cannot be exact, more objective measures of prematurity are commonly used. The following criteria, observed either alone or in combination, have been more or less generally accepted as indicating or suggesting prematurity.[9]

1. A birth weight of 2,500 Gm. (5 lb., 8 oz.) or less
2. A crown-heel length of 47 cm. (18½ in.) or less
3. An occipitofrontal diameter of the head less than 11.5 cm. (4½ in.)
4. A head circumference less than 33 cm. (13 in.)
5. A thoracic circumference of less than 30 cm. (11¾ in.)
6. Disproportion between head and thoracic circumference

The single most widely accepted criterion is weight (paragraph (1) above). This is the definition used by the American Academy of Pediatrics regardless of the period of gestation. It permits the inclusion of certain full term infants whose physical and functional immaturity make them more like infants having had an intrauterine existence of less than 37 weeks.[1] This is the definition used throughout the following discussion. Other corroborative evidence of prematurity is absence of the centers of ossification for the cuboid bone and distal epiphysis of the femur, provided certain variations relative to race and sex are recognized (discussed in Chapter 8).

Clinical picture.—The clinical picture presented by the small premature infant is quite characteristic. The deficit of subcutaneous fat results in marked wrinkling of the skin, which is dull red and transparent, the superficial vessels being readily visible beneath it. There is often an abundant growth of lanugo, especially on the upper part of the face and extensor surfaces of the extremities. Small hemangiomas and nevi are common. The large head appears to be out of proportion to the relatively short neck and extremities and elongated trunk. The eyes seem prominent and widely spaced, while underdevelopment of the nasal bones results in a small, short nose. The ears are nearly devoid of cartilage. The tongue appears relatively large. The abdomen is protuberant because of poor muscle tone, and umbilical hernias are frequently seen. Some of the expected behavior patterns are discussed on page 36. It should be emphasized that the change from fetal to postnatal period is not sharply differentiated.

PHYSICAL GROWTH

For an outline of organ development and a consideration of the general body form of the late fetus and early neonate, the reader is referred to the tables and graphs in Chapter 3.

Accurate and recent information on the physical growth of premature infants is extremely meager. Often the studies carried out both in America and abroad have failed to take into account such important

variables as environment and nutrition, which have been shown to have considerable effect on gain in height and weight. With the constant increase in knowledge and improvement in the care and feeding of these infants, it seems probable that present-day statistics would show an impressive advance over the older figures. Unfortunately no large series has recently been reported.

Fetal measurements at various periods of gestation are given in Table 16. They provide some idea of measurements to be expected in the prematurely born infant and will aid in the determination of the approximate gestational period.

Ylppö[17] compared the data on his premature babies with available data on intrauterine growth and concluded that the premature infant

TABLE 16.—Fetal Measurements at Different Periods of Gestation

	20-24 Wk.	24-28 Wk.	28-32 Wk.	32-36 Wk.	36-40 Wk.
Av. weight, lb.	1.4- 2.2	2.2- 2.6	2.6- 3.5	3.5- 5.5	5.5- 7.5
Length, in.	11.0-13.4	13.9-15.0	15.4-16.9	18.1-18.9	18.9-20.7
Head circum., in.	7.5- 9.4	8.3-10.6	10.2-11.8	11.4-13.0	13.0-14.6
Chest circum., in.	6.3- 7.9	7.1- 9.1	8.3-10.6	9.8-12.6	12.6-13.8

tends to follow the laws of growth corresponding to conceptual age. However, growth is disturbed at first by extrauterine existence. Gordon and his co-workers[11] found that infants below 2,000 Gm. at birth and fed a formula of half-skimmed cow's milk, 120 calories per kilogram, gained weight more rapidly than would be expected for a normal fetus during the eighth lunar month. This was not true when human milk was fed a similar group. The smaller the infants, the more striking this difference in mean daily weight gain became. Such studies not only throw some doubt on Ylppö's observations but also show the effect of nutritional variations on the premature baby.

Nearly all reports agree that the time required for the premature infant to regain birth weight is longer than for the term infant. In general, the smaller the baby, the longer this period. Premature children weighing less than 1,500 Gm. (3.3 lb.) at birth gain weight less rapidly than heavier prematures and do not reach the mean weights noted for the latter group for several years. According to Hess,[12] from eight to 10 years elapse before the smallest prematures attain normal weight for age. Ylppö's[17] group, including all weights up to 2,500 Gm., required an average of four to five years to reach a normal weight (based mainly on studies prior to 1920). Blackfan and Yaglou[4] reported that their smaller

infants gained weight more rapidly in a conditioned nursery where the humidity was high than in an unconditioned nursery where the humidity was low. Among the larger infants (5 lb. or more) the findings were reversed.

The body length of the premature child remains below that of the average child for periods ranging from one to nine years, according to Hess[12] and Ylppö.[17] The smaller the infant, the longer the period extends. Comparison of growth in length for the first three months of life according to fetal age showed it to proceed at a much slower rate than during intrauterine life. The actual increase in length for infants of all fetal ages was greater in the second month than in the first, and still greater during the third month. The shorter the gestational age, the more rapid was the increase for healthy infants.

In general, there is good correlation between birth weight, length and head measurements. Clifford[6] reported that the occipitofrontal diameter of the head can be measured quite accurately in utero from roentgenograms. In his fairly large series he found that a diameter of less than 10 cm. indicated a fetus (or premature) weighing less than 1,800 Gm. (4 lb.). A diameter of 8 cm. or less was noted for fetuses under 1,360 Gm. (3 lb.). If these observations are confirmed they may provide a valuable means of estimating viability and the degree of maturity of the fetus. The average head circumference of premature infants remains below that of the term infant until about the middle of the second year, when little difference can be found. It has been stated that the growth of the head is relatively less retarded than growth in weight, length or circumference of the thorax.

Dunham[9] says that more important as a criterion for prematurity than either the head or the thoracic circumference alone is the relation of the two. In full term infants the average chest circumference is from 93 to nearly 100 per cent of the average head circumference. In premature infants the percentage is much lower, for the smaller infants being 83–85 and for infants up to 2,500 Gm. (5 lb. 8 oz.), varying up to 91. By six months after birth this discrepancy has largely disappeared in the premature who is progressing satisfactorily.

In summary, it may be said that our knowledge concerning physical growth of premature infants is incomplete and needs amplification. The effects of nutrition and environment should have further study. However, certain generalities regarding growth seem applicable in spite of the many

variables that must be recognized. There is a general consensus that postnatal growth of the premature differs from that of the term infant. Although this growth may be considerably influenced by many factors, the tendency is to follow the pattern of late fetal growth for several weeks or months after birth, depending on the degree of prematurity, rather than the pattern of growth of the full term infant. The final prognosis for attainment of normal physical measurements does not seem to be impaired by premature birth; however, an average period of two years for girls and three years for boys may intervene before that goal is reached. Negro and female infants are more mature per given weight than are white and male infants.

Studies of hospital statistics have shown that the percentage of deaths among premature infants is inversely proportional to the birth weight.

TABLE 17.—Prognosis and Survival of Prematures, 1940-45*

Weight Group, Gm.	Survival, %	Prognosis
2,001-2,500	94	excellent
1,501-2,000	84	good
1,000-1,500	53	fair
Less than 1,000	...	very poor

*From Dunham.[9]

Where accurate statistics are available, there has been a steady upward trend of the survival rate in the past 20 years. The improvement has been most pronounced in the smaller infants. Table 17 gives figures Dunham[9] compiled from several hospitals where premature care was of good quality.

MENTAL DEVELOPMENT

There is some disagreement as to the effect of prematurity on mental and emotional development. Most of the studies undertaken can be criticized for the small number of children included, the lack of control groups, the inadequacy of the sources of information and the failure to take into consideration the socioeconomic factors. There is, however, the general impression that otherwise uncomplicated prematurity is neither an advantage nor a handicap.[3, 12] Due allowance must be made for the degree of prematurity in evaluating development (see p. 98 for formula). If this is neglected the premature infant will appear to be retarded, especially during the first two years of life.[10] No significant relationship between birth weight and intelligence has been observed.

Some workers have reported an increased incidence of "nervous mannerisms" and behavior difficulties in children who were born prema-

turely. It has been suggested that such traits may be related to the apprehensive state that the birth engendered in the parents and the continued oversolicitude on the part of all members of the family. Comparison with siblings and other children during the first two years may be unfair to the child and give rise to needless anxiety in the parents. Benton[3] has concluded, however, that the development of such tendencies in prematures is not an established fact and that further investigation must be carried out before such an opinion can be accepted.

The foregoing statements regarding the prognosis for mental development of the premature pertain only to the uncomplicated case. It has long been recognized that intracranial hemorrhage with neurologic lesions is more common in prematures than in full term infants. The reasons for injury to the central nervous system are: fragility of the capillaries, prolonged prothrombin time, premature subjection of delicate tissues to the forces of labor, frequent breech presentation and occurrence of anoxia, sometimes for prolonged periods. In one series studied, this birth complication, with some evidence of permanent damage, occurred in 27 per cent of 250 prematures.[9] This figure is certainly high, but in the compilation of statistics we cannot fairly compare a total group of full term infants with a partial group of premature infants from which all abnormal subjects have been excluded. The present evidence, therefore, indicates that group for group the occurrence of mental deficiency, regardless of the immediate etiologic factors, is higher in premature than in full term infants.

PHYSIOLOGIC HANDICAPS OF THE PREMATURE

The difference in the patterns of growth of the full term and the premature infant has been described. The cause of this difference remains unknown. Some have ascribed it to the lack of exposure of the fetus to the high estrogen levels of the maternal organism found during late pregnancy.[9] No proof of this theory has been provided. It is certainly true that there is a relatively inadequate antenatal storage of minerals, protein, fat, vitamins and immune substances. These "nutritional" factors may be the more important of the various ones present in the premature infant which account for his peculiar early growth.

Physiologic immaturity renders the premature infant's organism less well equipped to cope with the external hazards encountered at birth, with the result that his capacity for adaptation is low and neonatal mortality is correspondingly high. Levine and Gordon[13] have furnished an

excellent outline of the major physiologic handicaps. Obviously the degrees of immaturity among infants vary and do not always correlate well with the weight of the infant under consideration. There is also a variation in the degree of immaturity of certain systems or organs.*

Respiration.—The respirations of the premature are irregular, rapid, often shallow and with periods of apnea. Cyanosis is common and easily precipitated. Aspiration pneumonia is much more common in this group than in any other. The probable or possible causes for respiratory difficulties are: (1) a high threshold of the respiratory center requiring stronger afferent stimuli for response and relatively weak and inefficient gag and cough reflexes; (2) reduced number of capillaries of both medulla and lungs which impedes exchange of gases and possibly other chemical substances which might act as stimuli to the respiratory center; (3) sparsity of pulmonary elastic tissue and otherwise anatomic immaturity of alveoli leading to slower and less complete expansion of the lungs; (4) feeble tonus and weak musculature of the thoracic cage and diaphragm which, together with (5) a soft thoracic cage, leads to reduced intrathoracic pressure; (6) partial persistence of the fetal type of hemoglobin that releases oxygen less readily, and a reduction of the content of carbonic anhydrase.

Temperature control.—Faulty temperature control is a prominent feature in the more immature babies. These factors are discussed in some detail on page 217.

Kidney function.—The kidneys in the premature are less efficient excretory organs than in the mature newborn. The available evidence suggests that the impairment of renal function is due mainly to a deficient glomerular filtration rate. This leads to a retention of acid metabolites, disturbances in the electrolyte and water balance leading to edema, and very possibly other important but more subtle changes (see also pp. 170 ff.).

Alimentary tract.—The premature infant who progresses satisfactorily grows more rapidly than the full term infant. This requires the ingestion, digestion, absorption and utilization of large quantities of food. The increased demand must be allowed in spite of less efficient gastrointestinal function. There are often weak sucking and swallowing reflexes which may be easily and quickly exhausted. The secretion of some digestive enzymes and hydrochloric acid is low. There is faulty absorption of fat

*Further discussion of these topics will be found in other chapters.

and fat-soluble vitamins. Of the main foodstuffs, however, the premature infant seems to be intolerant only of large amounts of fat, which are adequately split but are largely excreted in that form in the stool. Protein, carbohydrate and most minerals are easily and well utilized. Vomiting and diarrhea are complications that may arise from parenteral or enteral causes of a relatively minor degree as compared with the more mature infant. (See also Chapter 11, on nutrition in normal growth.)

Blood-vascular system.—Owing to deficient antenatal storage of iron and protein, anemia is common in nearly all prematures at some time during the early months of life. Other contributing factors of importance are: faulty hemopoiesis, possibly related to a paucity of bone marrow; immaturity of enzyme systems and of blood-forming centers; increased destruction of embryonal cells; rapid rate of growth with its unnatural demands on the organism; a relative hydremia which exaggerates existing anemia, and an increased susceptibility to infection which impairs blood formation.

The hemorrhagic manifestations so frequently encountered are due primarily to increased capillary fragility and hypoprothrombinemia. There is a lessened degree of elasticity of the vascular tissue, and the frequent episodes of anoxia which may be present undoubtedly have a deleterious effect on the integrity of the capillary walls. The fluctuations of prothrombin content, often to very low levels, may reflect poor storage of vitamin K, liver immaturity or impaired absorption of vitamin K, or possibly all of these factors. The low reserves of vitamin C may also play a part in the bleeding tendency.

Hepatic immaturity.—The role of the liver in hypoprothrombinemia was mentioned in the preceding paragraph. Other evidence of immaturity of this vital organ in the premature infant includes: jaundice due to hyperbilirubinemia which is caused by an inability of the liver to excrete adequately the pigment liberated from the destroyed red blood cells; hypoglycemia, which is in part due to rapid exhaustion of limited stores of glycogen; and hypoproteinemia, leading to edema and susceptibility to infection. In part, the edema is also due to abnormal water balance and increased capillary permeability.

Infections.—The premature baby has a pronounced lack of resistance to infection. His tendency to an edematous condition leads to easier trauma of the skin and consequently greater susceptibility to exogenous factors. Poor temperature control may also add to a lowering of his resistance. Of

perhaps greatest importance is the lack of immune substances due to reduced opportunity for antenatal transfer from the maternal system and an inability to manufacture them in his own body. This last factor is concerned not only with hepatic immaturity and lowered protein production but also with hormonal and enzyme system deficiencies which are known to play an important role in immune body formation.

The tendency of premature infants to the development of rickets may be due to several causes. Their requirements for vitamin D appear to be greater than those of full term infants. In addition, there has been less antenatal storage of calcium and phosphorus and there is a great demand for all of these owing to the rapid rate of body growth. It has also been suggested that impaired renal function may cause a relative lack of tubular reabsorption of phosphates. Finally, the poor utilization of fat may lead to decreased absorption of vitamin D from the gastrointestinal tract.

A better knowledge of the peculiarities of growth and development of the premature infant will serve to explain the high neonatal mortality rate and help us to combat it. Of equal urgency, but not discussed here for obvious reasons, is a more complete knowledge of the cause and prevention of prematurity.[2] It is easily seen from the information now available that much study and continued accumulation of data are necessary for a thorough understanding of the many problems that the premature infant presents.

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6

Behavioral Development

Behavior may be defined as any observable response which is mediated through the neuromotor system. In the evaluation of developmental status, an estimate of the behavioral maturity is as important as an estimate of physical maturity. Normal behavior depends on an intact and functioning nervous system, which is to a large extent the prime regulator of bodily functions and activities and which controls the individual's ability to respond favorably to his environment. Since the degree to which behavior can deviate and still be within normal limits is of much less magnitude than that of anatomic measures of maturity, an accurate estimate of behavioral maturity is essential to the evaluation of normal development and the prognosis of any deviation from normal.

"Behavior grows. . . . . Behavior assumes characteristic patterns as it grows."[6] Growth is an orderly process which may vary in rate with the individual but which nevertheless progresses according to a lawful plan. Its observable patterns are an expression of the fundamental maturity of the neuromotor system. Further, behavior reflects the endowment (or inherited capacity), the integrity of the equipment and the experience (environmental factors) of the organism. The developmental diagnosis of behavior may be considered a form of pediatric clinical neurology whose function is to assess and interpret the maturity of the central nervous system.

"MEASURING" BEHAVIOR

Behavior norms have been established which can be used as a frame of reference in the evaluation of the behavior patterns observed. These patterns may be considered to be so many symptoms which have to be interpreted in the *clinical* diagnosis of normality and deviations from

normality. Since growth is a complex process and behavior an expression of complex interactions, diagnosis depends on the total picture presented and requires consideration of four major fields of behavior.

1. Motor behavior is the usual starting point in assessing maturity and includes gross posturing of the head, trunk and extremities as well as the finer manipulations. It is of unusual interest because of its neurologic implications.

2. Adaptive behavior includes sensorimotor co-ordination, manipulation and exploitation of objects, the use of motor capacities in the solution of practical problems and resourcefulness in utilizing past experience in adjusting to new situations.

3. Language includes vocalizations, single words and combinations in addition to facial and manual cues indicating wants as well as understanding of the expressions of others.

4. Personal-social behavior has much wider variation and depends to a larger extent on culture and environment, but its expression is also a function of neuromotor maturity. It includes feeding and sleep habits, bladder and bowel function, sense of ownership and the ability to work and play with others and to adapt to the regulations imposed by society.

Emotional behavior, although it is manifested through lower centers of the brain, also undergoes a developmental growth process. While it is not as easily accessible to measurement, maturational factors can be recognized in the varied reactions of the organism to similar stimuli at different ages. The fundamental emotional pattern pervades all behavior and manifests itself as differences in response, tempo and feeling tone.

Adaptive behavior is the most important field and is the best index of inherent capabilities. It approaches most closely what is usually considered "intelligence," but a developmental examination should not be considered to yield an intelligence quotient in the ordinary sense of the word. Intelligence tests as now constituted tend to measure limited functions, whereas a developmental examination tends to reflect all of behavior. "Mental growth" is a composite of growth as measured in the four major fields of behavior and is a reflection of maturational and integrative processes occurring in the central nervous system.

EVALUATION OF THE EXAMINATION

"Functional tests of behavior define the integrity and maturity of the nervous system."[6] The developmental examination appears as a play period

to the child being examined but is actually a standardized clinical examination, the results of which are as subject to interpretation as are those of any other examination. The procedure should be flexible and suited to the needs of the individual infant or child but should adhere basically to the form which has been devised and should not be a loose period of free play. The observed behavior can then be compared with the established behavior norms and conclusions drawn.

Since development progresses at an orderly rate, there is a constant relationship between developmental age and chronological age, and this can be termed the developmental quotient:[6]

$$\text{D.Q.} = \frac{\text{maturity age}}{\text{chronological age}} \times 100$$

This is not arrived at by a simple addition of pluses and minuses on a score sheet but is a *clinical* estimate of maturity based on the over-all picture. Although development is lawful, it does not necessarily progress at the same rate in each field of behavior, and it is necessary to assign a D. Q. to each of the four major fields, again based on clinical experience. The D. Q. is of diagnostic and prognostic significance, but it does not in itself yield a diagnosis. A diagnosis can be made only by a *clinical* evaluation of all of the aspects of development, with due consideration of history as well as of aspects of stability, security and personality that manifest themselves during an examination as readily as do walking and talking.

NORMS OF DEVELOPMENT

Development progresses in a cephalocaudal direction, control of the eyes coming first, followed by control of the head, arms, trunk and legs. Figure 15 illustrates the general trend and the major achievements at various age levels.[4]

Behavior norms for various key ages are presented later. In the first year of life development is estimated in terms of weeks rather than months because it is so rapid in early life that monthly intervals give a grossly inaccurate picture. Six months may mean 24 weeks of age or 30 weeks of age, and the developmental change in that period is tremendous. For rough judgment it is not necessary to learn behavior norms for every four week interval. If the key ages (which are at 12 week intervals in the first year) are kept in mind, it is a simple matter to say that a 20 week old child is behaving like a 16 week old child but a little better, while a 24

week old child more closely resembles a 28 week old child but has not matured quite enough to give a full picture of 28 week old behavior. The ages which will be discussed are 4, 16, 28, 40 and 52 weeks, 15 months (not a "key" age but much more of a turning point in development than

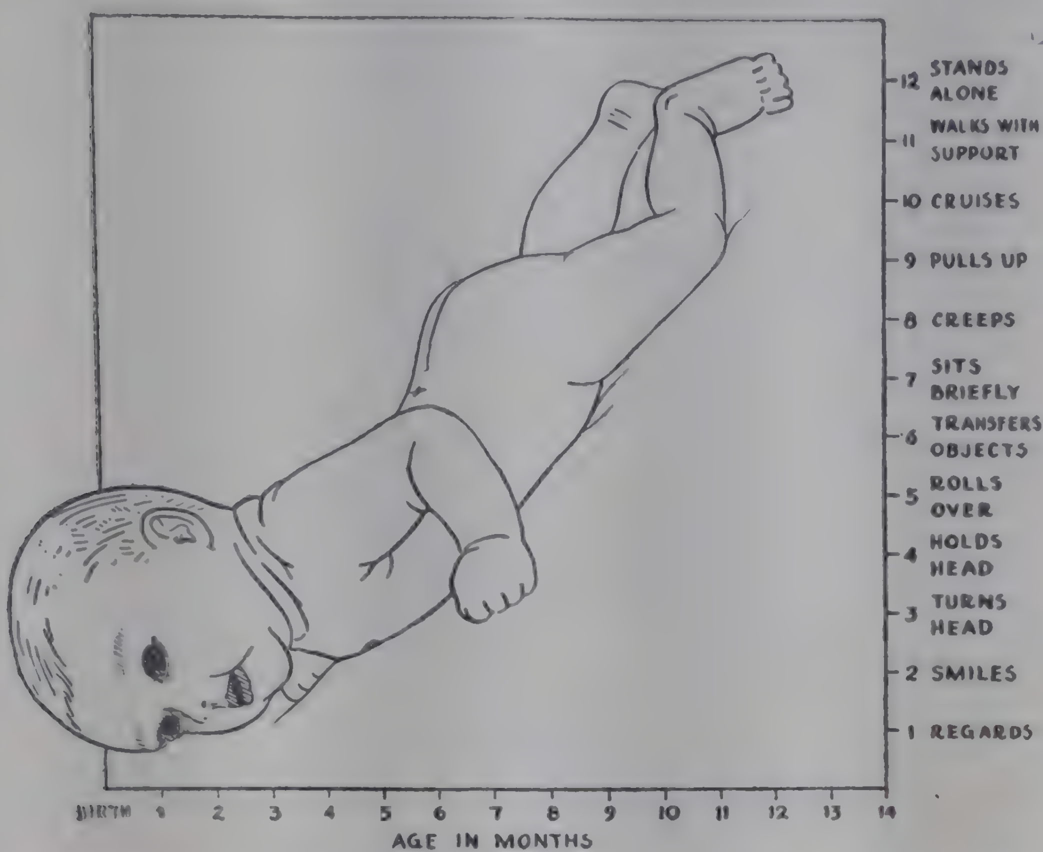

Fig. 15.—Developmental diagram for the first year of life. The infant's figure represents a diagonal line on which is plotted the progress of behavior (right of the diagram) against chronological age. The cephalocaudal pattern of behavior is diagrammatically illustrated by position of the figure. (After Aldrich's developmental graph for the first year of life.)

52 weeks), 18 months and 2, 3, 4 and 5 years. Some items are presented at the 6 year level. It should be understood that the behavior patterns given below represent average performance for a large group of healthy subjects. An individual pattern might deviate from these standards and still be within normal limits. In other words, the tabulation is not to be used as an inflexible rule of measurement.

4 Weeks

Motor:
1. Tonic neck reflex positions predominate
2. Hands fisted
3. Head sags

Adaptive:
1. Regards object in line of vision only
2. Follows to midline
3. Drops toy immediately

Language:
1. Vague indirect regard
2. Small throaty noises

Personal-social:
1. Stares indefinitely at surroundings
2. Regards face and diminishes activity

16 Weeks

Motor:
1. Symmetrical postures predominate
2. Head steady in sitting
3. Head lifted 90 degrees when prone; on forearms
4. Hands engage

Adaptive:
1. Eyes follow slowly moving object well
2. Arms activate on sight of dangling toy
3. Regards toy in hand and takes to mouth
4. Regard goes from hand to object when sitting

Language:
1. Laughs aloud
2. Excites and breathes heavily

Personal-social:
1. Spontaneous social smile
2. Hand play; mutual fingering
3. Pulls dress over face

28 Weeks

Motor:
1. Sits briefly leaning forward on hands
2. Bounces actively on standing
3. Has a radial palmar grasp of toys

Adaptive:
1. One-hand approach and grasp of toy
2. Bangs and shakes a rattle
3. Transfers a toy from one hand to the other

Language:
1. Vocalizes m-m-m when crying
2. Makes polysyllabic vowel sounds

Personal-social:
1. Takes feet to mouth
2. Reaches for and pats mirror image

40 Weeks

Motor:
1. Sits indefinitely steady
2. Creeps and pulls to feet at rail
3. Crude release of a toy

Adaptive:	1. Matches 2 objects
	2. Index finger approach
	3. Spontaneously rings bell
Language:	1. Says "mama" and "dada" with meaning
	2. One other word or equivalent
Personal-social:	1. Waves "bye-bye" and pat-a-cakes (or other nursery trick)
	2. Feeds self a cracker and holds own bottle

52 Weeks

Motor:	1. Walks with 1 hand held
	2. Stands momentarily alone
Adaptive:	1. Tries to build tower of 2 cubes
	2. Releases cube in cup (after demonstration)
	3. Serial play with objects
Language:	1. Two words besides "mama" and "dada"
	2. Gives a toy on request or gesture
Personal-social:	1. Takes a toy to the mirror
	2. Co-operates in dressing

15 Months

Motor:	1. Toddles
	2. Creeps upstairs
	3. Puts a pellet into the bottle
Adaptive:	1. Builds a tower of 2 cubes
	2. Puts 6 cubes in and out of cup
	3. Imitates a scribble
Language:	1. Jargons
	2. Four to 5 words, including names
	3. Pats pictures in a book
Personal-social:	1. Says "thank-you" or equivalent
	2. Points or vocalizes wants
	3. Casts objects in play or refusal
	4. Indicates when wet
	5. Nursing bottle discarded

18 Months

Motor:	1. Walks, seldom falling
	2. Seats self in small chair and climbs into adult chair
	3. Hurls ball
	4. Turns pages of book 2–3 at once

Adaptive:
1. Builds a tower of 3–4 cubes
2. Imitates a stroke with a crayon
3. Dumps pellet from bottle

Language:
1. Has 10 words
2. Looks selectively at pictures and identifies 1
3. Names ball and carries out 2 directions ("on the table," "to mother")

Personal-social:
1. Pulls toy on string
2. Carries and hugs doll
3. Toilet habits regulated in daytime

2 Years

Motor:
1. Runs well, no falling
2. Goes up and down stairs alone
3. Kicks a large ball

Adaptive:
1. Builds tower of 6–7 cubes
2. Alines cubes for a train
3. Imitates vertical and circular strokes

Language:
1. Uses pronouns
2. Three-word sentences; jargon discarded
3. Carries out 4 directions with ball ("on the table," "on the chair," "to mother," "to me")

Personal-social:
1. Verbalizes toilet needs consistently
2. Pulls on a simple garment
3. Refers to self by name
4. Plays with domestic mimicry

3 Years

Motor:
1. Alternates feet going upstairs
2. Jumps from bottom step
3. Rides tricycle, using pedals

Adaptive:
1. Builds tower of 9–10 cubes
2. Imitates 3-cube bridge
3. Names own drawing
4. Copies a circle and imitates a cross

Language:
1. Uses plurals
2. Gives action in a picture book
3. Gives sex and full name
4. Obeys 2 prepositional commands ("on," "under")

Personal-social:
1. Feeds self well
2. Puts on shoes and unbuttons buttons
3. Knows a few rhymes or songs
4. Understands taking turns

4 Years

Motor:
1. Walks downstairs alternating feet
2. Hops on 1 foot
3. Throws ball overhand

Adaptive:
1. Draws man with 2 parts
2. Copies a cross
3. Counts 3 objects with correct pointing
4. Imitates 5-cube gate

Language:
1. Names 1 or more colors accurately
2. Obeys 5 prepositional commands ("on," "under," "in back," "in front," "beside")

Personal-social:
1. Washes and dries face and hands; brushes teeth
2. Distinguishes front from back of clothes
3. Laces shoes
4. Goes on errands outside of home

5 Years

Motor:
1. Skips, alternating feet
2. Stands on 1 foot more than 8 seconds

Adaptive:
1. Builds 2 steps with cubes
2. Draws unmistakable man with body, head, etc.
3. Copies triangle
4. Counts 10 objects correctly

Language:
1. Knows 4 colors
2. Names penny, nickel, dime
3. Descriptive comment on pictures
4. Carries out 3 commissions

Personal-social:
1. Dresses and undresses without assistance
2. Asks meaning of words
3. Prints a few words

6 Years

Motor:
1. Advanced throwing

Adaptive:	1. Builds 3 steps with blocks
	2. Draws man with neck, hands and clothes
	3. Adds and subtracts within 5
	4. Repeats 4 digits
Language:	Use Sanford-Binet items (vocabulary)
Personal-social:	1. Ties shoelaces
	2. Differentiates A.M. and P.M.
	3. Knows own right from left
	4. Counts to 30

The minimal materials needed for carrying out an examination are: rattle, bell, 10 cubes, cup, pellets, bottle, ball, picture book, paper and crayons.

The development of cube behavior is presented here in some detail to illustrate how behavior grows and the complex neuromotor mechanisms involved. It shows also how many details of developmental processes are known; not only in the field of cube behavior has such a fine dissection been done, but in all the other aspects of growth too.

Not until 12 weeks of age can the infant sit supported with his head bobbingly erect and fix his eyes briefly on so small an object as a cube, involving as it does control of the eye muscles and some control of the neck muscles. At 16 weeks of age he is able to hold his head steady and regard the cube promptly and for a prolonged period. The eyes still have the lead, but the beginnings of eye-hand co-ordination may be seen as he looks from hand to object and back again. At 20 weeks he activates his arms on sight of the cube but grasps it on contact only and not with intent. When it is placed in his hand he holds it precariously with an ulnar-palmar grasp. At 24 weeks control of the hands is progressing, and he approaches the cube on sight but with a crude, bilateral corralling motion. He grasps the cube palmwise, takes it to his mouth and retrieves it when he drops it.

At 28 weeks of age, eye-hand co-ordination is quite well developed, and the child makes an immediate one-hand approach on the cube on sight. This is the beginning of handedness, but it is in a very rudimentary stage; and the 28 week old infant shows his bilaterality in his transfer of the cube from one hand to another. The first concepts of release are appearing, in an extremely crude form, as he passes and repasses the cube from one hand to the other. Just before this age there was a crude transfer which consisted of one hand pulling the toy out of the other hand. The

combination of perception and manipulation is very active, and the infant regards the cube intently as he takes the cube from mouth to tabletop with each hand alternately. Fine prehension is developing and the beginning of the specialization of the radial digits is seen as he takes the cube with a radial-palmar grasp. He is able to hold a cube in each hand more than momentarily, but not until 32 weeks of age is he able to secure first one cube, then a second cube, as it is presented to him. He is unable to release one of these to pick up the third cube which is placed before him, since the pattern for release is present only in connection grasp, as shown by transfer. At 36 weeks of age he has made further advance and picks up the third cube after dropping one from a hand, and he has discarded the palmar grasp, using the radial digits to pick up objects. A sense of combining is beginning to develop as he hits a cube on the table with a cube in his hand, and brings a cube held in one hand against the rim of a cup held in the other. At 32 weeks he merely regarded the cup as he held the cubes, or dropped the cubes to take the cup.

At 40 weeks of age there is a further advance in specialization of the radial digits as evidenced by index finger approach, with poking and probing. He now combines two objects more definitely, matching two cubes in his hands. A dim awareness of dimension is developing as he first notices the cube which the examiner has dropped into the cup, and he reaches in and fingers it. Crude release of the cubes, independent of grasp, has developed, and he no longer simply drops them to the table. At 44 weeks he has a greater sense of depth, and of container and contained, for he removes a cube from the cup although still unable to release a cube into it, merely thrusting hand and cube into the cup. At 48 weeks a new feature develops in serial play with a number of cubes, the rudiments of counting, and his horizon is widening as he takes the cubes from the table to his chair in succession. By 52 weeks release has developed to the point where he can release one cube into the cup after demonstration, but fine motor control is not accurate enough to enable him to release one cube on top of another, although he tries to build a tower. At 56 weeks his sense of container and contained is great enough to enable him to place a cube in the cup on request without demonstration.

By 15 months release has come sufficiently under voluntary control to allow him to build a tower of two cubes. He exhibits his new-found power by casting cubes to the floor and putting five or six cubes in the cup. But his attention wanders and his drive is not sustained enough for him to

complete the task, and he begins to take the cubes out. Not until 18 months does he have the sense of completing a task so that he fills the cup with the cubes. Fine motor control has further progressed so that he builds a tower of three or four cubes before it falls. This fine motor control grows slowly, and it takes him another six months to add three more cubes to his tower, making one of six or seven cubes at 24 months. Not until 36 months is he precise enough to add the final three cubes for a tower of nine or 10. At 24 months, also, he is beginning to master the horizontal as well as the vertical direction as he alines two or three cubes to form a train. Not until 30 months, however, is he able to combine vertical and horizontal by adding a chimney to the train, and the more complex combination of vertical and horizontal directions in the three cube bridge comes at 36 months.

EMOTIONAL DEVELOPMENT

Of all the aspects of behavior, those which are the most difficult to classify and to grade are the emotions. In infants and children particularly, the overt responses to different stimuli may so closely simulate one another that one cannot differentiate the nature or degree of the cause by simple observation of the response. Even the adult has considerable difficulty in describing his own "feelings" or emotions. Furthermore, the reactions to emotions are so modified by experience, training, sense of values, social and economic status and the available means of expression (movements, language, facial contortions, etc.) that any attempt at accurate measurement is nearly impossible. As a single example, it has been shown that the number and distribution of outbursts of anger in a group of children are influenced by hunger and fatigue. Nevertheless, some generalizations are possible.

As the child grows his expressional behavior becomes more refined. He acquires means of control and uses an increasing number of words and gestures as symbols of his emotional life. In the newborn period there is one universal response or unlearned emotional reaction. This is the so-called "startle pattern" in response to sudden noise or sudden release of support.[13] The usual manifestation is a generalized, somewhat aimless activity of the musculature, or the Moro reflex, described more fully on page 144. Such reactions as "fear," "rage" and "love" are not clearly exhibited by all infants, at least not in a form recognizable as such by adults.[13] As the child becomes older he manifests an increasing repertoire of emo-

tional responses and they are elicited by a wide range of objects and situations which originally were ineffective. Concurrently with experience there is an elimination of emotional responses to some objects and situations. Thus, emotional behavior, like any other behavior, undergoes a process of maturation which is dependent on growth and development of the individual.

One extremely important part of personality development that begins very early in life is ego perception or the awareness of the individual as being himself and different from others. The primary unit of which the infant is first conscious is himself and the mother or her substitute. Until about 3 months of age there is no recognition of the mother on the part of the baby, and he is usually satisfied if properly cared for, regardless of who does it. There is nothing in the baby's action that seems to anticipate his mother's approach or feeding. He suffers from hunger and gives a hunger cry. By 3 months he may stop crying as the mother approaches or show other evidence of recognition that his wants are to be satisfied. He thus shows ability to separate himself from the mother. This development is naturally dependent on the general process of maturation and the beginning of recall or memory. It is the earliest indication of the mechanism of identification or the discrimination between self and the outer world. The baby is beginning to distinguish what is literally "him" and "not him."

The ego has been defined as the seat of consciousness, and it controls voluntary actions. As it develops it becomes of sufficient strength to tolerate many unpleasant inner tensions and keep them suppressed until satisfaction is possible. Thus, by 3 months the infant can on occasion stop his hunger cry in anticipation, by his mother's approach, that his need will be gratified. It is probable that not until the child is 3 or 4 years old is ego perception completed so far as distinguishing himself as a separate entity. This learning process is in part stimulated by deprivation from his mother and may manifest itself by dependency on his mother and the fear of strangers which is so notable at age 7 and 8 months.

It is through still further ego development that socialization becomes a prominent part of the child's life. At an average age of 3 or 4 years, group play and true and sustained socialization first take place. As already mentioned, it is at this time that recognition of the self as a complete entity is attained.

Among the two strongest fears manifested by children are those of separation and injury to self. At least some explanation of the former has

been developed through the concept of ego development. Fear of being hurt, fear of blood, fear of fire, which are often evident at 3 and 4 years, are explained as being based on similar ideas, i.e., loss of identity by losing part of oneself. The ritualistic and repetitive type of play often indulged in at these ages are simply a method of gaining confidence and self-assurance. These types of fears are usually well resolved by the well adjusted school-age child. For these reasons, elective surgery is inadvisable until after these resolutions have taken place.

The cause of violent emotional responses is not always apparent or does not seem logical to the observing adult. It can be stated that sudden and unexpected changes elicit this type of reaction more often than gradual transition. It must be realized that from the child's standpoint there is a reason for his behavior. If the usual order of dressing or preparing for bed is disturbed, for example, it may send the child into a typical temper tantrum even though the change may have seemed perfectly reasonable and logical to the parent. The child, however, is firmly convinced that "the right shoe must be taken off before the left!"

In the following outline we make no attempt to cover the entire range of emotional responses, nor should it be taken too literally. There are many variables both in the individual and in the situation. The behavior patterns listed may be considered the usual and more characteristic repertoire.

1–4 weeks: Hunger cry; startle response; much or all of crying is tearless.

4–8 weeks: Begins differential crying for different causes, e.g., hunger, before sleep, pain; vocalizes happily; smiles.

8–16 weeks: Smiles at face; laughs aloud; amount of crying reduced.

6 months: Cries easily on slight provocation, e.g., change of position, removal of play object, unusual sounds; plays contentedly alone; thrashes arms and legs when frustrated.

7–8 months: Shows fear of strangers; affection or love of family group appears; emotional instability shown by easy and quick changes from crying to laughing.

1 year: Enjoys simple tricks or games; may cry for affection; crying more often associated with irritation or minor frustrations than formerly; stiffens in resistance.

18 months: Self-contained; a new awareness of strangers; beginning favoritism for toys; tantrums if things go wrong.

2 years: Improved emotional equilibrium; number of relatively violent emotional reactions begins to decrease; voice tone used symbolically; pride in accomplishment of motor skills and clothing; can be coy in actions and facial expressions; fears mainly auditory; may fear parents' leaving.

3 years: Begins to enjoy co-operative and group play; more independent and less tearful than a year earlier; ritualistic in many activities, e.g., in dressing, arranging toys, going to bed; friendly and desires to please; may be jealous of siblings; much laughter with play; humor related to both gross activity and verbal play; increasing emotional control; fewer fears than at 2 years and now they are mainly visual, e.g., the grotesque, the dark, animals.

4 years: Somewhat argumentative, but this often used as play and in desire to experience use of new words and new actions; selfish; impatient; pride in accomplishments; humor boisterous and exaggerated; likes to show off; tattles often; boasts; if associated with older children may be mildly profane or obscene; aggressive physically as well as verbally; rough and careless on occasions with toys; fears are much the same as at 2 and 3 years, but now enjoys being mildly "frightened" in play with adults; strong feeling of "me," "mine" and "I" and of home and family; begins to distinguish self from others and to recognize other people as entities; brief and superficial self-criticism.

CLINICAL APPLICATIONS

Sound familiarity with the normal pattern of development is of vital importance because of its clinical usefulness in evaluating reduced, impaired or deflected development. There are several important fields of clinical application.[6]

A. Primary amentia. In this condition there is symmetrical retardation in the developmental rate from birth, and it can be diagnosed in the early weeks of life. Endowment here is limited at birth, and potentialities for normal growth have never been present.

B. Cerebral damage to an originally or potentially normal brain.

This is manifested by selective and unsymmetrical deviations from normal development.

C. Deflections in development due to impaired experience. Special sensory handicaps such as blindness or deafness, environmental impoverishment due to highly unfavorable institutional life or family conditions, glandular deficiencies and severe systemic illnesses play an important role.

D. Superiority. This attribute often but not invariably manifests itself in acceleration in the first two years of life, but the quality of behavior is always enhanced and the responses to the examination situation are described in terms usually appropriate to the later years, such as self-possessed, sophisticated and discerning. One needs to be very cautious about making a diagnosis of superior development in early life.

E. Adoptions. An ability to evaluate the normality of an infant is essential to placing babies in adoption. Although superiority cannot be diagnosed in the first two or three years of life, subnormal development is easily recognized. Adoption work should be carried out only by properly qualified social agencies, but the pediatrician may be confronted by a situation in which a couple has already taken a child into the home. His knowledge of development may frequently save the parents and the child much grief.

The following list will be of use in classifying defects and deviations in development.

I. Defective development (amentia, mental deficiency, feeblemindedness)
  A. Primary
    Simple deficiency
    Aplasias and malformations
    Degenerative diseases
  B. Secondary to destructive lesions caused by
    Trauma
    Hemorrhage
    Infections
    Toxic agents
    Anoxemia
    Irradiation
  C. Mixed types
    Combined primary and secondary
    Combined primary and symptomatic

II. Deviated development: symptomatic retardations and deformations due to
- Prematurity
- Endocrine dysfunction
- Selective sensory handicaps
- Selective motor handicaps
- Abnormal experience: deprivation or stress
- Personality defects: congenital or acquired
- Mixed types: any combination of symptomatic causes

Once a diagnosis of amentia has been made, the pediatrician has the most important task of imparting it to the parents tactfully but firmly and of following through so that the parents accept the diagnosis and prognosis. He then has to help them make a realistic adjustment to the facts of the situation in the interests of the entire family group. Practically without exception, children with mental development of imbecile or idiot level should be placed in an institution for custodial care.

GUIDANCE DURING INFANCY AND THE PRESCHOOL PERIOD

An understanding of the fact that behavior is a manifestation of the maturity of the nervous system is extremely useful in the handling of many of the common problems of bringing up children and can be important in preventing the development of behavior abnormalities in later life and in fostering secure and stable development.[1, 5, 16]

The developmental point of view should be transmitted by the pediatrician to the parents, who should be encouraged to consider management of their children in terms of their present capabilities and to anticipate their developing needs. The children should be treated as individual human beings with desires and needs which are dependent on maturity and which are just as real as adult desires and needs. An understanding and anticipation of a child's needs in terms of maturity will not "spoil" him but will encourage security and make him independent and self-sufficient at a much earlier age.

1. Feeding. Unless a child has some organic disease he will present a feeding problem only because some adult has tried, usually in early infancy, to impose his own ideas of how much should be eaten. An infant should be fed on a self-demand schedule, since he has the same physiologic variations in appetite as an adult. Solid foods should not be forced in infancy; if they are, refusal of them will often spread to include refusal

of all food. In later infancy and childhood certain foods will be refused in spells, and these refusals should be respected: diets can be balanced by substitution of foods which are acceptable at the moment. The period of physiologic anorexia which often appears during the second and third years should be anticipated and recognized as such. If parents accept the basic principle that a child should eat because he wants to, a minimal number of feeding problems will develop. Self-feeding and weaning should also be encouraged when a child indicates his readiness.

2. Sleep. This is also a developmental function that depends on maturity. It varies considerably with the individual child's personality and is related to a satisfaction of social needs and the child's ability to leave his parents. In the neonatal period sleep can barely be distinguished from waking periods. Toward the end of the first year the child is fearful of being deserted by his mother and he can no longer simply be dumped into bed and left abruptly as he could be a short while before. At 2 the child is well aware of being part of the family group and will use any ruse he can think of at bedtime to come back into the family circle. At 3 sleep is frequently disturbed at night, and it is common for children to wander about or want to sleep with their parents. All of these phases can be anticipated and can be viewed as part of a normal developmental sequence which need not become a permanent problem if they are recognizd and understood.

3. Bowel and bladder control. These are dependent to a large extent on complex neuromotor mechanisms involving an ability to retain and release. Training should be approached with a very casual and matter-of-fact attitude. The early successes should be recognized for what they are—the mother's ability to anticipate the child's needs and to "catch" them. As he grows older (12–16 months) he will learn to retain urine but will be unable to release it voluntarily, and success will diminish. Refusal to void at this age is not deliberate naughtiness but evidence of neuromotor immaturity. Release will gradually be acquired (18–21 months), but the responsibility will still be the mother's until the child acquires sufficient control to verbalize his needs on time (24–27 months). Toilet regulation should not be undertaken vigorously, particularly when the child is unable to co-operate, and failure should never be greeted with disapproval or punishment.

4. Dependency and co-operativeness. The young infant is very undiscriminating, and not until 20–24 weeks of age does he recognize strangers.

By 40–52 weeks he is beginning to make a distinction between himself and his mother, but he is unable to do this clearly and consequently becomes greatly upset when she steps out of the room. If his wishes are considered and his mother allows him to creep around after her, this stage of extreme dependency passes. By 2 years he shows increasing signs of his sense of individuality but not enough to enable him to share his possessions. He has a great sense of "mine" but very little of "yours." At 2½ he is seemingly very contrary, simply because he cannot make a choice of alternatives. By 3 he has matured sufficiently so that he can take turns, co-operate with other children and be very anxious to conform to the social conventions (but he goes through more complex disorganized stages again later before he finally stabilizes). If these maturational factors are understood and the child is handled accordingly, he will grow out of his phases of negativism and become a secure and stable individual.

THE CHILD DURING THE EARLY SCHOOL YEARS

In the period from 6 to about 11 years of age the child learns about the outside world and becomes increasingly independent of his parents. He develops a conscience or a sense of responsibility about matters that to him seem important. These are the years when closely knit groups are formed such as clubs and gangs. During this period the child is introduced to the culture of his society through the public or private school. They are important years for learning how to get along with other people and to abide by the rules of society.

The child's independence of his parents is manifested by his gaining a feeling of individuality and by his desire to be treated as a person rather than as a possession. He is apt to show some impatience toward his parents who keep telling him the right things to do. Although he loves them as much as ever, he dislikes emotional display about himself. Joining a club is simply another means of showing his ability to accomplish things independently of adults.

His sense of responsibility is manifested in competitive types of games or ones that require some skill. He becomes a small businessman by setting up a lemonade stand or by starting a garden. He may not carry many of these enterprises through to completion, but the urge to do them is present.

Toward the end of this period he thinks in terms of cause and effect and acquires an insight into the actions of machines and some of the

fundamentals of human relationships. The desire to accomplish great things occupies his mind when he is not doing school- or homework. He dreams of bold adventures, and one of his favorite heroes may well be a character in a comic strip or story where right always wins. Besides the comics, books, radio, television and motion pictures furnish him with his ideals.

Because of his desire for independence he may be irritating to his parents and present a problem in discipline. The adult must try to overlook some of his less serious bad habits and, when giving orders, try to be matter of fact and friendly. Most obnoxious to the child is the "bossiness" or the nagging voice, which one should strive to avoid. School problems are best taken up with the teacher or school authorities. Poor work in school may be due to many causes such as physical defects, poor eyesight or hearing and extreme "nervousness." The highly intelligent child may be bored with his schoolwork, while the child with a low intelligence cannot comprehend his studies. Finally, the school system may be at fault. One should carefully examine and eliminate any or all possible causes instead of punishing the child.

In the following paragraphs are given guides to expected behavior in children for each of the ages listed. It must be stressed that each child has an individual pattern of growth which is unique to him or her. The traits listed, therefore, are not to be taken too rigidly nor as absolute models that all children will follow. They illustrate the behavior trends for each age. Such an outline may aid a physician or other interested person in judging very roughly the maturity level of a particular child. Under each age heading are two brief paragraphs. The first describes various factors of behavior such as play, eating, habits and relations to society. The second lists a few of the more readily tested accomplishments that can be used to appraise normality of development.[8, 20]

Five Year Old

Appetite is usually good, except perhaps for breakfast. The child is slow but persistent in eating and many other activities. He has considerable motor ability and skill. He is poised and controlled. He loves his home and persons and objects associated with it. The stage of the 4 year old runaway is passed. The outstanding fear of the 5 year old is loss of his mother. Fears of ghosts or bogeymen and unreal objects have greatly diminished in the past year. The child is serious about himself and concerned with his own

ability. He wants to assume responsibilities. He usually gets along with adults very well, although shy at the initial meeting. His memory for past events is surprisingly accurate. Play is apt to follow domestic patterns in both sexes. Both like to "play house" and dolls are favorite objects. He makes a good adjustment to school and enjoys the routine of planned programs.

He can name four or more colors, repeat a sentence of 10 or more syllables, tell which is the heavier of two weights or objects, reconstruct a rectangular card which has been cut diagonally into two pieces, draw a recognizable picture of a man with a body, head, etc., and can identify penny, nickel and dime.

Six Year Old

This is a period of physical and psychologic change. It is apt to be a difficult period for the parent who does not understand this transition. The child is restless and has difficulty in making decisions. Activity is almost constant. Appetite continues to be good. A characteristic in eating and nearly all other activity is that he is good at starting things but poor at finishing them. Accidents—spilling of milk, stuffing the mouth too full of food, etc.—are common at the table. Enuresis is rare now. The growing vocabulary includes slang and swearing. "Emotional storms" such as temper tantrums reach a peak at this age and may be difficult to control. Rudeness is another common and difficult problem. Behavior patterns are often explosive and seemingly unpredictable. Jealousy toward siblings is the rule and sibling play should be supervised. All play is more vigorous than in the 5 year old and imagination is a big factor. Several favorite radio programs are listened to religiously by many children. The majority like school and want to "learn." Parental love and praise are extremely important throughout this difficult period of growing up.

A vocabulary of about 2,500 words has been acquired. The child can define simple objects in terms of what they are used for, can count correctly to 20 or 30, knows right and left parts of body, knows number combinations making up to 10, draws a man with hitherto unadded features, e.g., neck, clothing and hands, and differentiates A.M. and P.M.

Seven Year Old

Play is approached more cautiously than when the child was 6. In all respects he is less of a "problem child" than one year before.

Although he has definite likes and dislikes, he is less vehement in expressing them: this is true of food, clothing, friends, play, and the like. The child needs only slight help in dressing and undressing and preparing for bed. Bowel and bladder training are complete and little conversation is directed toward these functions. He or she is aware of and sensitive about sex and in front of the opposite sex avoids self-exposure. Seven becomes a co-operative member of the family group. Neatness and alacrity in dressing or carrying out parental commands are frequently wanting. He is not entirely self-contained but he is very introspective and desires the approbation of his group and of his parents. One might call the seventh year a pensive one.

He can count by 2's and 5's and grasps the basic idea of addition and subtraction, can tell time, often knows what month it is, can copy a diamond accurately, repeats five numbers in series, e.g., 4, 7, 9, 3, 2, and repeats three of them backward.

Eight Year Old

The eight year old's movements increase in "smoothness" and "poise." These words in a large measure describe this age. Yet unsupervised play of a large group may become extremely rowdy, with reversion to "animal spirits." He dislikes being alone and wants his companions to take an interest in his activities, either actively or as interested observers. Segregation of the sexes for the first time becomes important in the choice of playmates and groups. His best behavior is often away from home or when strangers are in the home. Comic books may be his favorite reading, but he is beginning to expand his reading interests. Eight enjoys school and dislikes staying at home. Individual differences are great, but in general this is an age of broadening experiences and exploration intellectually.

He now knows the days of the week; he can count backward from 20 to 1; he can make change for small amounts of money; he is skeptical of the realness of characters in stories and on radio programs; comprehension of far-off places has begun, and he describes differences and similarities between two things from memory, e.g., bird and butterfly, wood and stone, dog and cat.

Nine Year Old

This is an intermediate age—between childhood and the beginnings of adolescence. The child has a better hold on himself and is seeking and

acquiring new forms of independence. He has a growing capacity to complete tasks that he sets for himself or that are expected from him. Even short interruptions will not interfere, for he will return to his work or play. He looks to the future and plans ahead for work and play. He is mature enough to accept blame, and alibiing of the infantile type is less indulged in than formerly. He is essentially truthful and honest. Eating is much neater than formerly and manners are usually well observed. Waking during the night, which was present from 4 or 5 on, is now uncommon. Dressing is completed without aid. He obeys well and can assume many responsibilities. He will show disgust at both siblings and parents if they do not act as he feels they should. Hero-worship has become prominent. The 9 year old is self-sufficient, self-critical, but not severely so, and he is anxious to please. The sexes remain well separated at parties and other social gatherings. It is usually not difficult to discipline him. His reading material is more realistic than before, although he may still enjoy comic books. His literary interests reflect his general character, a fluctuation between childhood and youth in his thoughts and actions.

He describes objects in detail and does not just tell what they are used for; he knows the day of the month and year, tells time well, arranges weights in the order of heaviness and can do simple multiplication and division.

Ten Year Old

One of the fundamental changes at this age is the beginning of differences in attitudes toward sex. The girl at this age is definitely more mature and poised than the boy. Both are beginning to think about social problems and are eager to discuss them. The power of suggestion, for good or evil, would seem to have its greatest influence at this time. It is at the start of adolescence that the formation of good or bad "character" may be most readily accomplished. Teachers, parents, physicians and social service workers should be cognizant of these facts and use them to their best advantage. The conception of individuality, both in himself and in others, is more developed now than previously. Personality traits and abilities become manifest at 10 and give fair indication of what the adult will be like. Teamwork, submission to fixed rules in play, is now possible.

He uses numbers beyond 100 with understanding, can use simple fractions, repeats six digits forward, copies a simple design after 10 seconds' examination and repeats a 20 syllable sentence.

Eleven Year Old

By this age the girls are falling behind boys somewhat in physical strength and endurance. Girls are apt to be taller than boys at this age and for the next two to three years, owing to the earlier adolescent growth spurt in the female. Membership in groups and clubs is increasing in importance. Children of this age group enjoy taking part in school and community "drives," e.g., paper collection, Red Cross collection, etc. Team games are very popular. If present, shyness may increase and be a difficult problem for some parents to understand. The child is more critical of the products of his labors than ever before. There is an increasing urge for some financial independence from the parents, with the result that he or she will readily take on small jobs after school and during vacations.

He can define some abstract terms, e.g., "justice," "honesty" and "revenge"; he can point out the meaning or moral in fables and can explain the necessity of hygienic measures such as covering the mouth when coughing. It must be realized that by this age the variability of individual interests and the diversity of intellectual pursuits render standardization by simple tests very difficult and of questionable value for the average child.

THE ADOLESCENT CHILD

The problems of the adolescent boy or girl are much too broad to cover here, but some of the characteristics of behavior and mental development should be outlined for the sake of completeness. This is an age group that has in the past been largely neglected by both the pediatrician and the internist but has furnished ample material for the pseudopsychologist, the philosopher and the poet. It would seem most logical for the pediatrician to follow the child through this period, for he is most likely to understand the developmental background leading up to the time of full maturity.

One must always realize that each child is an individual and that he or she will mature at his or her own rate of progress, with structural and functional attributes that are peculiar to the individual's constitution, heredity and environment. The child must attempt to live with organ systems and functional capacities of widely varying levels of maturity throughout adolescence. Frequently the individual tries to "live up" to that which is most advanced, such as stature. His parents and teachers too often

expect him to act according to his most advanced development. These incongruities may be a serious hazard when other factors such as muscular development and emotional maturation are still juvenile. The adolescent is primarily concerned with conforming with his own age group and achieving a measure of independence from his parents which he feels is necessary as a step toward the attainment of adulthood.

The process of sexual maturation not only involves structural and physiologic changes but brings with it a series of perplexing and sometimes highly disturbing emotional and social problems. Personal appearance of the individual becomes in many children a source of great conflict. There is apt to be a greater emphasis on "good looks" and on a "normal" physique and anatomy than at any other period in life. Perhaps unfortunately, society in general has so impressed the child with normality that he becomes overanxious about his own body and its functions and yet is most reticent to converse about it.

The adolescent is easily hurt when criticized. He feels that he is "grown up," but lacks the experience and knowledge of the adult. He will fluctuate between resentment of parental advice and his desire to fall back on his family when he has some problem. He may develop rather romantic ideas about people or become somewhat obsessed with certain ideals. The adolescent girl is apt to have "crushes" on her teachers. There may be certain social difficulties in the schoolroom owing to the fact that at this time the girls usually are two or three years ahead of the boys in stature and emotional development.

Many of the individual difficulties which appear at this age are the result of conflict between the child and other members of society. Pressure is put on him to assume various adult responsibilities, and his own desires about his future form still another, and perhaps more important, "inner" pressure. The former may come from parents, friends or society in general. Limitations to the accomplishments of the individual are the results of these two pressures plus his socioeconomic status, his level of intelligence and what he is able to achieve throughout this period. It is this relationship between his own aims in life, the aims that others force upon him, his current or past performances and his sense of satisfaction or frustration pertaining to these performances that will greatly influence his emotional development. The tendency of the adolescent, continually faced with failure owing to the conventions of society or parental misunderstanding, is to react with aggressive rebellion. This leads to further difficulties and a

vicious circle results. Maladjustments are much greater among boys and girls who do not have close, harmonious relationships with their parents and among those whose parents are in discord with each other.

For the normally developing adolescent, acceptance by the social group in which he lives is a very dominant and personal drive. When he is deprived of this acceptance and has not found some measure of success in his group he often withdraws to himself. Such a child needs help in improving social technics, or perhaps it would be best to transfer him to a more congenial or otherwise more suitable group. The method of "buying" him into the social group by furnishing him with the biggest and best bicycles, automobiles, etc., a method sometimes used by parents, usually ends in failure for the child. If the boy or girl, with the aid of understanding parents, can objectively see his own successes and failures throughout childhood, he or she can nearly always take minor failures in their stride in the more sensitive period of adolescence. Children should be taught to make a sensible evaluation of their liabilities and assets progressively throughout childhood. They should also be acquainted with the fact that there are both "good" and "bad" in the world, that there are privilege and underprivilege, honesty and dishonesty, charity and wicked selfishness. A realistic philosophy of life is needed, but also one that furnishes them with a motivation to accomplish the best of which they are capable.

In view of what has been said, it should be mentioned that most psychologists feel that some pressure on children for success and attainment, if it is compatible with the child's ability, is both desirable and necessary.[19] Such pressure will produce a kind of anxiety in the child that leads to socially acceptable behavior. Whether one agrees with what is considered "socially acceptable behavior" is unfortunately beside the point. The important fact is that the child must live with society and, for his greatest happiness, this must be done on the terms that society forces upon him.

Sex is not a problem limited to the adolescent period, yet it is often felt to be of prime importance at this time. The sexual education of the child has proceeded some considerable degree before adolescence is reached, whether or not this is accomplished by the parents. The first questions, particularly when a new baby arrives, are most likely to come at about 3 or 4 years. Until the preadolescent years it is probably wisest to give information only when it is sought. The answer should be straightforward and in terms simple enough that the child can understand. Detailed ex-

planations are not needed, for the child requires only a simple statement and is not yet interested about details. If the parents feel incompetent to answer such questions because of emotional or idealistic conflict or because of inability to give a concise forthright answer, the physician should be consulted. Ideally, before adolescence is reached the child should be well oriented as to the anatomic and functional differences of the sexes. Such information may best be given as a part of the general instruction in anatomy and physiology which naturally must be kept on an easily understood level. A clear conception should be given of ovulation, fertilization, pregnancy and birth. Menstruation should be explained before, not after, it occurs in the girl. Nocturnal emission may better be explained to the boy as he approaches puberty. However, one must not overstimulate latent interests unduly, and good judgment concerning each individual must be used. For instance, in dealing with masturbation, no good is served unless anxiety is alleviated, but too permissive an attitude tends to break down the normal defense against such activity.

The fact that marriage must be delayed until economic independence is obtained is one of the greatest difficulties which modern society has placed in the path of the adolescent. Further, any sexual activity before marriage is socially and religiously forbidden. Early in the adolescent period each boy and girl usually passes through a homosexual period of development. During this time the child often forms romantic or emotional attachments to a person of his own sex and usually of his own age. Hero-worship of an older person may also occur. This period is said to be one of "rediscovery" of oneself. Overt physical sexual experiences among boys are not uncommon, and a smaller number of girls participate.[19] As a usual thing, when there is an adequate association with the opposite sex the homosexual phase is rapidly passed through and the heterosexual phase is entered. This period is characterized by such phenomena as the "puppy love" affairs. It is during this important time that parents and physicians can be of great aid in establishing in the youth the gradual acquisition of the correct attitudes and feelings toward acceptance of the sex role. Caution is necessary in order not to disgust or frighten these future parents by unwarranted lectures on the sins of pregnancy out of wedlock and the horrors of venereal diseases. Ways can be found to help the adolescent in learning about love, marriage and parenthood. Often, parents cannot do the most suitable job in discussing these problems with their own children. Schools, churches and youth organizations are accepting the re-

sponsibility of this problem in ever-increasing degree. Physicians and psychologists are participating in such programs. Finally, there are a few really adequate books specifically written for boys and girls of different ages which discuss this frequently complex and confused problem.* Parents are often in need of education also. It has been repeatedly stressed that the background experienced by the child, as reflected in his parents' attitude and behavior, is extremely important in his sexual adjustment.

The most important obligation of the pediatrician during this period of life is to realize the conflict that is going on in the child. As Thom[18] has so well stated, it is the pediatrician who must attempt to help the child over this difficult hurdle. He must help the child grasp the idea that freedom carries with it obligations and responsibilities; he must in turn help parents to understand that the ultimate goal is to train their child to live happily and efficiently in a world that will grant no special concessions.

Parents must recognize and accept changing relationships between themselves and their children. This amounts to a steadily growing equality. In addition, parents and educators must realize that social, economic and moral values change with each new generation and that these are dynamic, not static. One psychologist points out that many of the rules for adolescents are set up by adults who have never satisfactorily established a set of rules for themselves. The adult must serve as an experienced guide who has the advantage of mature ability and greater information in most spheres. There must at the same time be an equality of human dignity and personal integrity between the adult and the child.

In conclusion, a word of caution should be offered to the reader. It might appear from what has been said that the adolescent period is one of great storm and stress. Although this may be true in isolated cases, it should be emphasized that the majority of children go through this time of life with comparative ease and with few serious scars carried over into adult life. Overemphasis to parents or children as to the possible difficulties that may be encountered has frequently done more harm than good. A common-sense attitude must be taken and individual problems appropriately dealt with as they arise.[12, 18, 19]

*Among such books are: *Human Growth: The Story of How Life Begins and Goes on*, by L. F. Beck and M. Robinson (New York: Harcourt, Brace and Company, Inc.), for ages 12-17; *The Stork Didn't Bring You*, by L. Pemberton (New York: Hermitage Press), for ages 12-17; *A Baby Is Born*, by M. I. Levine and J. Seligman (New York: Simon & Schuster, Inc.), for ages 7-10; *The Story of Life*, by T. Rice (Chicago: American Medical Association), for ages 9-12; *Pocket Book of Baby and Child Care*, by Benjamin Spock (New York: Pocket Books, Inc.), a guide to parents.

BASIC NEEDS OF EVERY CHILD

Nearly every child psychologist and pediatrician has at one time or another attempted to formulate what he considers to be the basic needs or emotional requirements of the child. The authors do not pretend that the following list is complete or the final answer to the problem but feel that recognition of these factors is an important step in the attainment of a happy and well adjusted child.

1. Security and a feeling of belonging to the family and social group. Each child needs not only love but also firm kindly guidance. Letting the child do whatever he wants to do and whenever he wants to do it must eventually lead to a feeling that his adults are unconcerned, and he develops a sense of insecurity.

2. Adaptability or learning to live with the world as it is. In part, this means conforming with the group. In part, it means facing reality. It does not mean complete and unquestioned acquiescence to the forces of environment.

3. Self-expression and freedom to show one's individuality. Each child should be allowed to "daydream" and use his imagination. Perhaps one of the greatest faults of modern educational methods is the rigidity of planned activity which allows little time for the child's own self-directed activity. Guidance does not mean planning or constant direction and advice. Experience is still a good teacher, though sometimes a hard one.

4. Achievement of success in both large and small matters. Allowing the child some self-expression often leads to his finding his own best capabilities. Praise on the part of the parents and teachers should be real and always commensurate with the task achieved. False praise seldom fools a child.

SLEEP

The pattern of sleep of each infant and child is a varied one, and we have already stated that some understanding of this fact is necessary for proper guidance of the child's behavior. Sleep is important to the conservation of energy needed for growth and repair. The metabolic rate falls below basal levels during quiet sleep, and respiration and circulation as well as many other physiologic processes are slowed.

Most of the infant's time is spent in sleep. Signs of increasing maturity are reduction of total sleeping time and increase of the length of time be-

tween sleeping periods. During the first few months, from 18 to 20 hours are spent in sleep and may be even greater for the small premature infant. By 3 months of age the infant will sleep on the average about 16 hours of a day and will often sleep through the night, although this may not be true of some normal infants for another two or three months. By 1 year of age the child sleeps from 14 to 16 hours, and by 2 years from 12 to 14 hours. Of this total time, from one to two hours will be taken up in daytime naps. The requirement of a nap may be eliminated by a few children as early as 3½ years, but more often it is not omitted until he approaches 5 years. By the time the nursery school period has been reached (4–5 years), he may be napping only three to five times a week. The amount of sleep required then gradually declines so that 10 hours at 12 years is average and eight to nine hours at age 17. Any given child may vary in his requirements from day to day.

It is impossible to answer the question, "How long should my child sleep?" Perhaps the best plan, and certainly the one which reduces the number of so-called behavior problems related to it, is that of self-regulation. This takes into account the individual requirements and allows for normal maturation. To promote sound sleep it is always wise to avoid overstimulation before the child goes to bed. Nor should being put to bed be used as a form of punishment, as this immediately sets up a highly undesirable association which may last a long time. Dreams and nightmares or night-terrors are not uncommon in mild form, beginning about the second or third year and often subsiding to a great extent by the fifth or sixth year. The child may be restless or even awaken crying due to such episodes. Unless they occur frequently and are persistent, such behavior need not be considered alarming. Awakening due to wetting of the bed is not uncommon during late infancy and early childhood. By 3 or 4 years the child usually sleeps through the night without having to get up to urinate. By 5 years and thereafter, sleep through the night is usually deep, quiet and peaceful.

At 18 months sleep may be resisted for some time after the child is put to bed. He often delays sleep by crying for his mother or, a little later, by demanding a drink of water and the like. Taking a favorite toy or some other object to bed with him is common from about 1½ through 3 or 4 years. Certainly no harm can arise from such a practice and it often serves to quiet the child and better prepare him for sleep. Various methods are resorted to by the young child to resist sleep in addition to those

enumerated. These may include head-rolling, head-banging, singing, talking and thumb-sucking. They are so common and occur in so many well adjusted children that they hardly deserve more attention than mere mention of the fact that they do occur and eventually are given up. The use of restraints or punishment to abolish such behavior always leads to further management difficulties. If let alone the child will "outgrow" these mannerisms by 3 or 4 years of age, although an occasional brief lapse into such action may again appear at times of emotional tension, such as the arrival of another sibling.[5, 16]

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7

Organ Development

Development implies an increase in complexity, differentiation and function as opposed to growth, meaning an increase in size. It is possible to have considerable development with very little growth in size, as, for example, during the first days following fertilization of the ovum before implantation has occurred and in instances when the growth of a child is checked by a pathologic condition such as rickets. Each individual is endowed by heredity with certain potentialities for growth and development which may be more or less than average.

THE EMBRYO

During the fourth week of development, when the ovum is about as large as a grape, the main organ systems become established.[45] The neural folds come together and, by fusing, form the neural tube from which the central nervous system is derived. The remaining parts of the germ disk become the skin (ectoderm) that covers the body of the embryo, portions of it contributing to the special sense organs and to the buccal cavity. The dorsal portion of the yolk sac provides the gut (entoderm), later forming pharyngeal structures, lungs and hepatic tissue. The mesoblast cells between entoderm and ectoderm, by proliferation and differentiation, form the somites, body cavities, and the circulatory system and their supporting tissues. The processes of differentiation take place in a wavelike manner in a craniocaudal direction. When the embryo is 9 mm. long (6 weeks) its primary anatomy is established and the arm buds are just making their appearance. During the second month occur all those changes in form and differentiation that convert the 3-4 mm. embryo to the fetus measuring 30 mm.

MUSCULATURE

The development of muscle fibers takes place in premuscular mesodermic tissue. The early growth of voluntary muscle is both hyperplastic and hypertrophic for the fibers increase both in number and in size. From the middle of prenatal life to early maturity the growth of skeletal muscle forms the largest part of the increment of the body. In the middle of prenatal life, skeletal musculature forms about one sixth of the body weight; at birth, one fifth to one fourth; in early adolescence, one third, and in early maturity, two fifths. The gain in musculature in childhood and adolescence is about equal to the growth of all other organs, systems and tissues combined.[57]

It can be seen that the maximal growth in muscle mass occurs relatively late and follows chronologically the maximal growth in height. It has been found that strength virtually doubles between 12 and 16 years, but the peak increase tends to follow the major increments of height and weight. Tests of motor ability and co-ordination do not confirm the widely held view that a loss of motor control and awkwardness are associated with the adolescent growth spurt. On the contrary, there is a constant and steady improvement during this period.

CUTANEOUS STRUCTURES

The skin of the newborn is thin and easily traumatized. It is covered with varying amounts of the cheeselike material, vernix caseosa. This covering appears to have some beneficial properties in protecting the infant from superficial infection. There is a considerable amount of fine hair, or lanugo, over the body. It may be more abundant in the premature than in the full term infant and is lost during the first weeks of life. The superficial vessels are prominent, giving a ruddy appearance to the entire body. Small areas of telangiectasis are commonly present at the base of the nose and over the occiput. These are considered by some to represent true vascular nevi, but they usually disappear entirely by the end of the first year of life. During the first few days following birth in the full term neonate and for longer periods in the prematurely born, there may be periodic episodes of acrocyanosis which have little or no clinical significance at this time. Mild forms of milia (obstruction of the sebaceous glands) and sudamina (obstruction of the sweat glands) may be apparent on the nose and cheeks throughout the neonatal period. They are seen as small white,

millet-seed–sized, raised areas and are mainly important in differentiation from a pustular dermatitis. Desquamation during the first few weeks after birth may be pronounced.

The nails of the smallest premature infants are often imperfectly formed and very soft. In contrast, the full term baby has well formed nails which are firm. The hair on the head is usually lost during early infancy to be replaced, at considerably varying intervals of time and occasionally extending into the second year, by the permanent hair. This is usually more coarse than the initial hair that it replaces. With increasing age, and especially during adolescence, hair growth is heavier. The first appearance of pubic, axillary and most of the more prominent body hair is influenced by sexual development (see p. 211).

Both sweat and sebaceous glands are present in the fetus but they have little function until a month or more following birth. This is an important factor in the poor regulation of body temperature in the full term and premature infant. Both types of glands undergo considerable development during adolescence. Following puberty, certain specialized types of sweat glands in the axillae and labia of girls undergo cyclic changes associated with menstruation.

The prepuce is usually adherent to the glans and remains so for some time after birth. The skin of the external genitalia, axillae and areolae becomes pigmented with the development of secondary sexual characteristics associated with the beginning of adolescence.

We have seen that one of the prominent changes in the last trimester of gestation is the addition of subcutaneous fat. Along with a poorly developed sweating mechanism, the failure to accumulate a full quota of subcutaneous fat is a real liability to the premature in maintaining an even body temperature. Such tissue is an important means of insulation against environment. The thickness of the subcutaneous fat increases throughout the first year. It is this accumulation plus the prominent abdomen that gives the infant his rotund appearance. During the second year there is a definite decrease in this tissue. It is important for both the physician and the parents to realize that this change takes place and that it often coincides with the period when the infant begins to display disinterest toward his food. There is a more gradual loss of adipose tissue during the next few years. At the beginning of adolescence, and throughout this period, there is a reaccumulation of subcutaneous fat, which is more pronounced in girls than in boys. The amount present is quite var-

iable and may be relatively slight, especially in boys. There are two methods by which the amount of subcutaneous material may be measured: one is by skin calipers and the other is by roentgenology.[50, 57]

SKELETON*

The state of skeletal calcification which has already taken place in the newborn infant depends on (1) the state of maternal calcification, (2) blood calcium and phosphorus ratios, (3) blood calcium and protein ratios and (4) balance of calcium, phosphorus and vitamin D intake of the mother during gestation. Following birth, the factors which were dependent on the maternal metabolism are naturally removed, but additional ones then come into play.[20] These are discussed at some length in connection with the parathyroid glands (p. 204) and calcium and phosphorus metabolism (p. 238 f.).

The human skeleton passes through the successive stages of connective tissue, cartilage and bone, and no part of the original membranous skeleton persists to adult life; the fontanels of childhood are examples of the last remaining vestiges of the original connective tissue. Cartilage is found in all parts of the skeleton, even where bone is to be laid down directly in membrane, such as the clavicle and cranial vault. The duration of the cartilaginous stage is a rough measure of the relative speed of development. The more rapidly a part is growing, the less time occupied by the cartilaginous phase.

From birth to 4 years, the cut surface of a long bone shows a pink texture of trabeculae interspersed with rich red marrow. From 4 to 7 years, fat gradually accumulates in droplets, and by 7 years the bony trabeculae have given place to a real marrow cavity. Between 12 and 14 years there is a patch of fat in the midlength of the bone, extending toward both extremities. Changes in the epiphyses of the long bones are comparable to those in the shaft, but the bone trabeculae do not become absorbed, and fatty changes are completed by 19 or 20 years. These changes closely parallel the dates of fusion of the epiphyses except in the upper part of the femur. Tibia, sternum, pelvic bones and vertebrae contain red marrow throughout life, and adult distribution is attained at about 25 years of age, which roughly corresponds to the date of fusion of their epiphyses.

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*See also Chapter 8, Osseous Development.

The epiphyses.—An epiphysis is a cartilaginous area present at each end of every long bone of the limbs, on the upper and lower faces of the vertebral bodies and in certain other locations where special processes are required for the attachment of muscles. If they ossify, as they usually do, the ossification develops from a special separate center and not by penetration from the main center of ossification for the bone. In general, epiphyses which commence to ossify early unite with the shafts late.

In the utilization of the features of ossification as indicators of age and bodily maturation, the following age limits are considered:[14, 57]

1. Birth to 5 years: registration of skeletal age by appearance of centers of ossification.

2. 5–14 years: registration of skeletal age by bony penetration of cartilaginous areas.

3. 14–25 years: registration of skeletal age by epiphyseal-diaphyseal union.

For data on epiphyseal union and appearance of ossification centers, see Tables 26, 28 and 30 (pp. 181, 187 and 188).

Disturbances of bone formation may be severe, as in certain endocrine disorders, or may be temporary, as in rickets. In achondroplasia and chondrodystrophia, minor degrees of the disease bring about partial inhibition with derangement of the growing areas. Local manifestations of disorder are seen in chronic osteochondritis, as Köhler's and Calvé-Legg-Perthes diseases, in which the center of ossification is flocculent. Simple repression of skeletal differentiation from which the patient can recover under suitable therapy is exemplified by hypothyroidism and juvenile diabetes.

Arrangement and Proportions of Skeletal Growth

At birth the chest is rounded, the shoulders are high and the neck is short. Between 3 and 10 years the proportions gradually change, with the chest becoming broader and relatively flat, the ribs sloping down more and the shoulders and manubrium dropping, with an increase in the apparent length of the neck. At birth the vertebral column shows only the forward concavities of the thoracic and sacral regions. As the child holds his head up, at about 3 months, the forward convexity of the cervical region appears. After the child learns to walk, the forward lumbar convexity develops and is not very far advanced at 3 years. These vertebral curves, being closely associated with balance and posture and therefore

responsive to the slightest stimulation, are not fully under voluntary control.

Growth of the skull.—The cranium consists of a bony shield or vault in which lies the brain. The superior and lateral walls are made up of the parietal, squamous and temporal bones, the floor by the greater wings of the sphenoid, the ethmoid and the occipital; the frontal and the remainder of the occipital bones complete the vault. There are eight significant sutures, two coronal, two lambdoidal, two squamous, the sagittal and the metopic (Fig. 16). The skull is much larger than the face in infancy, with

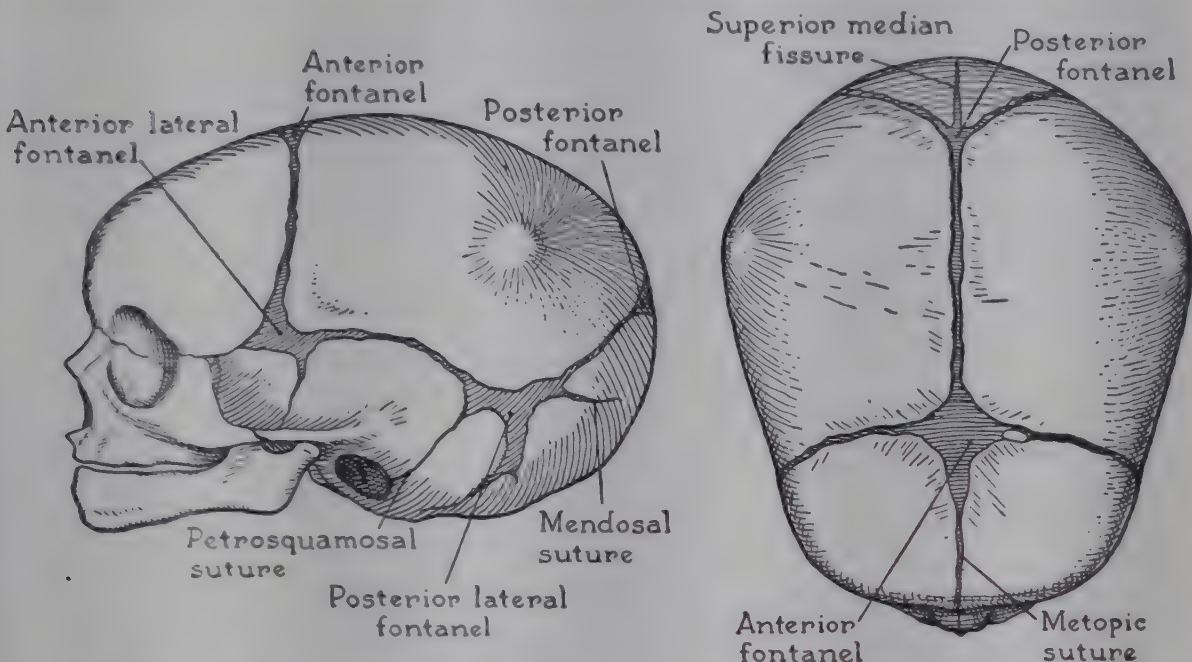

FIG. 16.—The cranium at birth, showing major sutures and fontanels. No attempt is made to show molding or overlapping of bones which sometimes occurs at birth. (From Caffey, J.: *Pediatric X-Ray Diagnosis* [2d ed.; Chicago: Year Book Publishers, Inc., 1950].)

the disproportion particularly striking in premature infants. Thus some hypognathia is normal in infancy, but severe hypognathia may endanger life because the tongue tends to drop back into the pharynx on inspiration and bring about suffocation by occluding the pharyngeal airway.

Skull bones are relatively soft at birth and are readily molded or flattened as the infant lies with the head turned to one side (tonic neck position). This somewhat unsightly flattening of the occipitoparietal area is so common at age 3-4 months that mothers worried lest the misshapen appearance continue should be given confident reassurance. They should be told that, except in retarded infants, the head will be symmetrical within the first year. Of course, genetic factors and familial

tendencies affect the shape of the skull. There is no correlation between head size and mental capacity, except that very small head size is often due to failure of brain development (microcephalus) and very large heads result from hydrocephalus, which nearly always causes some brain damage, though normal mentality may follow arrest of hydrocephalus in some instances.

The mechanism that produces normal suture closing is not clearly understood, and the time of life when this occurs is not fixed. It is believed that under normal conditions the mesenchymal tissue between the margins of the bones keeps them apart or at least delays their progress toward each other by continuous interstitial growth. When this interstitial tissue ceases to grow and ossifies, synostosis (bony union) takes place. The sutures between the bones of the calvarium do not become firmly closed until near puberty, and until then an increase of intracranial pressure may cause reopening of the sutures.

A statement regarding the possibility of premature union of sutures is pertinent. The suture most likely to unite prematurely is the occipitomastoid, next the sagittal, the squamous and coronal and, last, the lambdoidal. In these cases, union is completed before the age of 7 years. Premature closure of the various sutures gives rise to bizarre head shapes, the more common ones being designated by the descriptive terms scaphocephaly, oxycephaly and tower skull.

There are six fontanels at birth: anterior, posterior, two sphenoid and two mastoid, occurring at the junctions of the frontal and parietal bones, parietals with the occipital, parietal with sphenoid, and parietal with temporal, respectively (Fig. 16). Within a few months only the anterior fontanel remains palpable. This, the last to close, is shown by palpation to be obliterated between 10 and 16 months after birth in the normal child.

FACIAL GROWTH

Facial growth is divided into growth of the mask and the palate, the mask including the orbits and the nose. Vertical growth of the face occurs in spurts, related to respiratory needs and not to tooth development. These spurts occur during the first six months after birth, during the third and fourth years, from 7 to 11 years and again between 16 and 19 years. The first growth is olfactory, associated with vertical growth of the upper nose, the last is sexual, and the other two are conditioned by increasing respiratory needs of the growing body. The forward growth of the cranium,

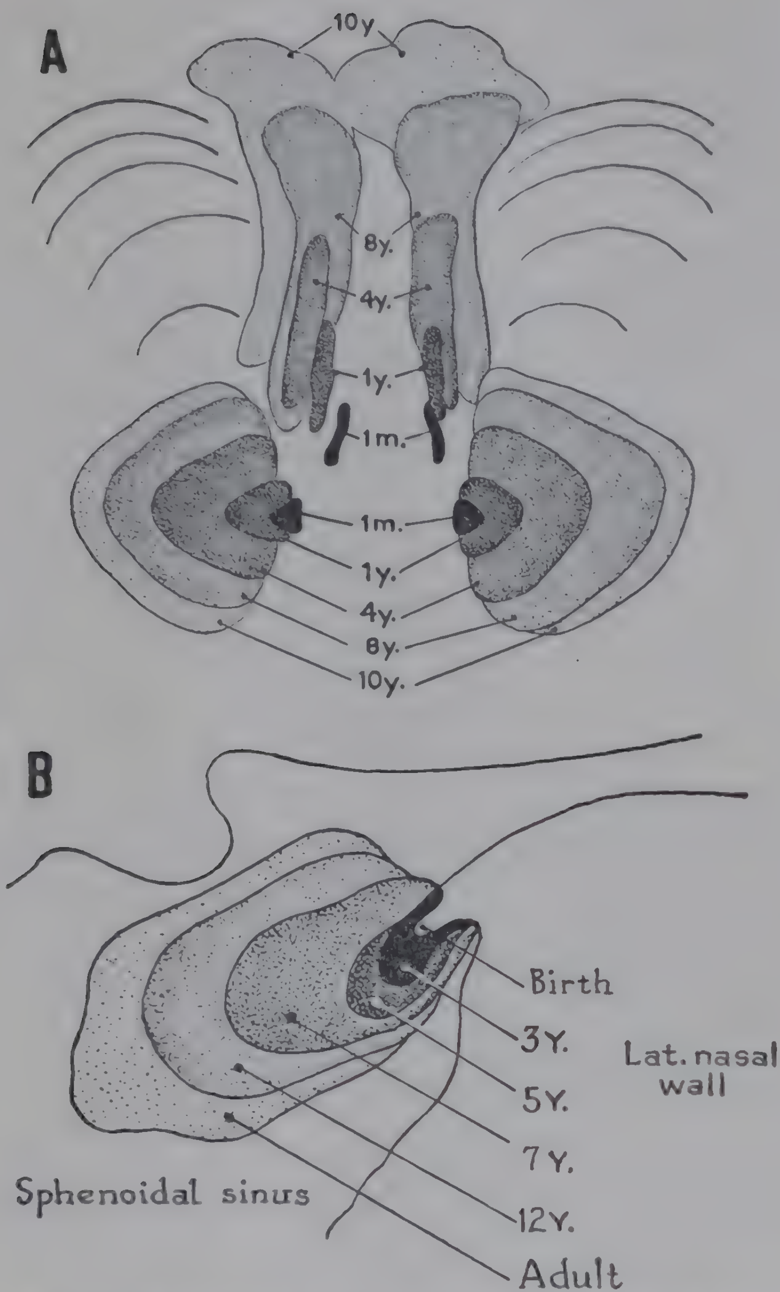

FIG. 17.—*A*, composite drawing showing changes in size and shape of maxillary and frontal sinuses during infancy and childhood. *m*, month; *y*, year. *B*, diagram illustrating postnatal growth of sphenoid sinus from birth to maturity. (Redrawn from Scammon in *Abt's Pediatrics*; from Caffey, J.: *Pediatric X-ray Diagnosis* [2d ed.; Chicago: Year Book Publishers, Inc., 1950].)

carrying with it the face, which has its own pattern of forward growth conditioned by dentition as well as by vertical growth, makes a complicated procedure in which individual variability must be expected.

The paranasal sinuses and mastoid process.—The bones of the face in the adult contain paired cavities known as the paranasal sinuses because of their close anatomic relation with the nasal cavities and the common origin of their linings from the nasal mucosa. The sinuses retain direct communication with the nasal or nasopharyngeal cavity by ostia, so that air, secretions and infections readily pass back and forth from nose to sinuses.

The anlagen of the sinuses are first found during the third fetal month when the face is taking on definitive characteristics. The sinuses are present at birth, though they develop and enlarge as the face grows in height and width during childhood (Fig. 17, *A* and *B*). The maxillary sinuses and ethmoid cells in the newborn *(C)* are so poorly developed and the contrast between facial bones and soft tissues is so slight that x-ray visualization is very difficult. At this time they are so widely open to the nasal cavity that their infection as a separate entity hardly exists. They continue to grow steadily until after puberty. The sphenoid sinuses do not grow rapidly until about the third year. The frontal sinuses are formed by enlargement and a kind of migration of ethmoid cells into the frontal bone; at birth they are represented only by shallow outpouchings of the nasal mucosa. On the average, the frontal sinuses are apparent above the nasion on x-ray films at age 3 (Fig. 17, *E*) and are at the level of the orbital roof by 6 or 7 years. There is considerable variation in size of the sinuses at any age, as seen in Figure 17, *D* and *E,* where the maxillary antrums in the 2 year old are better developed than in the child of 4. In general, the children with the smallest antrums in one age group will also have the smallest antrums in the following age groups. The frontal sinuses show more individual differences in size and shape than do any of the others and may be entirely absent in a small percentage.[41]

At birth, pneumatization of the temporal bone has barely begun, and there is but a single cell, the mastoid antrum, in communication with the superior part of the middle ear. The mastoid process itself is undeveloped at this time. Pneumatization of the temporal bone occurs by the progressive outgrowth of air cells from the mastoid antrum into the solid bone. The mastoid process begins to grow during the first year, but pneumatization of the tip is seldom demonstrable before the fifth year.[41]

For discussion of dentition, see Chapter 12.

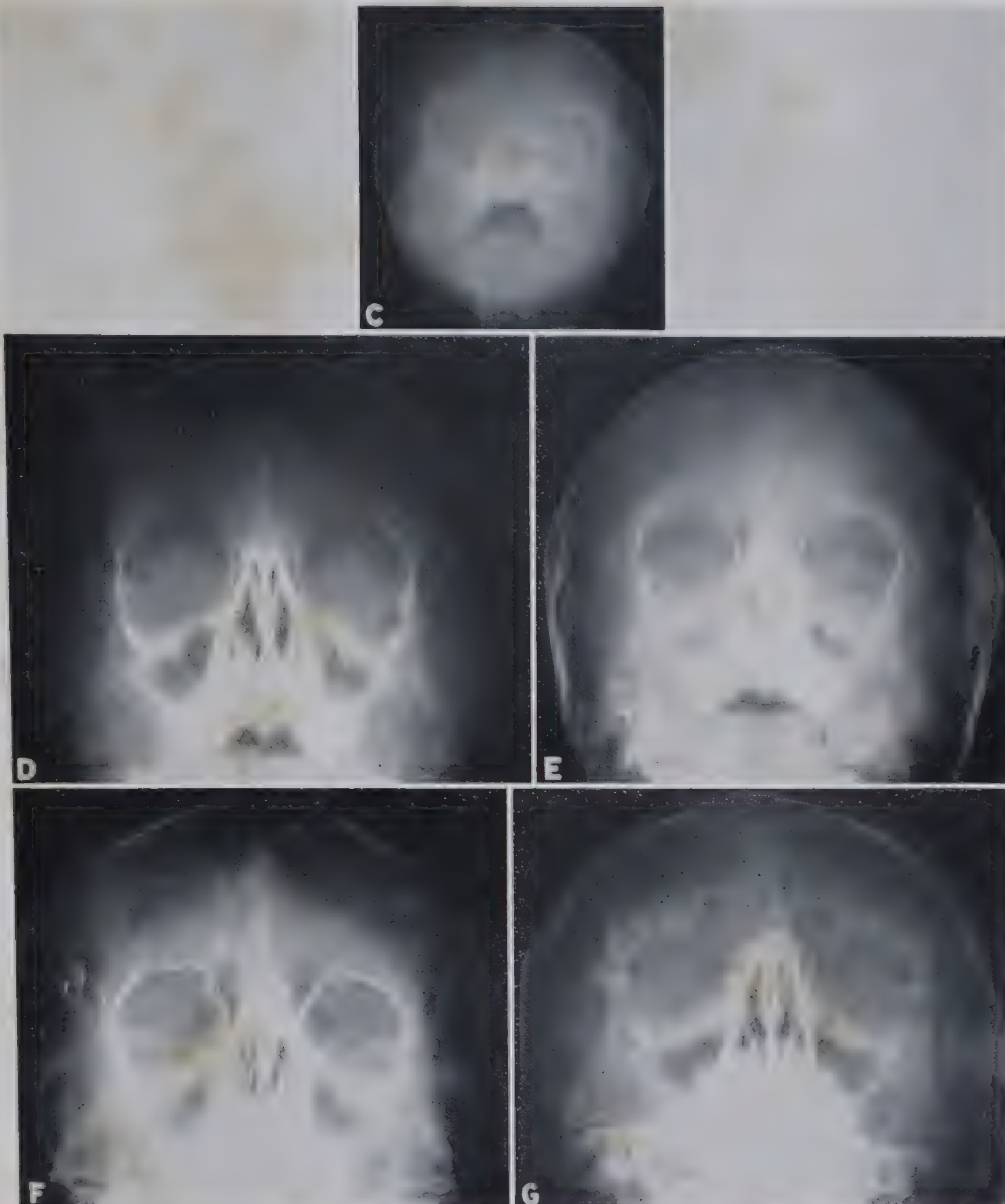

FIG. 17.—*C-G*, dorsoventral projections; sphenoid sinuses not visualized. *C*, newborn. *D*, 2 years. *E*, 4 years; definite budding upward from the ethmoids, the beginning of the frontal sinuses. *F*, 9 years; frontal sinuses have penetrated to a point above the supraorbital ridges. *G*, 12 years; sinuses are fully defined and pneumatization of zygoma appears as air-containing slits above maxillary antrums.

CENTRAL NERVOUS SYSTEM

The structure and function of the nervous system are more readily understood if we review some of its phylogenetic and embryonic development. In more primitive forms of life, such as the jellyfish, only a diffuse network of neurons exists. Stimulation of such an animal produces a diffuse and often inefficient response. In the earthworm a chain of ganglions has developed, and in the early chordate forms a simple neural tube associated with segmental nerves is present. Response to irritation in both of these forms increases in complexity and in the latter is segmental and more purposeful than the diffuse response displayed by lower forms of organisms. All vertebrates have an enlargement of the cephalic end of the neural tube, i.e., a brain, and in progress upward in the evolutionary scale the brain becomes relatively larger. In higher vertebrates the forebrain, especially the cerebral cortex, assumes a dominant role, reaching its greatest degree of complexity in man. With development of the brain there is superimposed on the segmental system a controlling influence. A repetition of this phylogenetic development can be seen in man.[26, 37]

The initial steps in the formation of the nervous system take place very early. An infolding of the thickened dorsal plate of the embryo forms the neural groove and then the neural tube with coincident separation from the parent ectoderm. Certain cells lying near the margin remain independent and assume a position on either side of the tube and just dorsal to it. They are the primordia of the sensory ganglions of the spinal and cranial nerves and indirectly of the sympathetic ganglions. The neural tube rapidly dilates anteriorly as the primordia of the brain; posteriorly it remains relatively uniform in size as the forerunner of the spinal cord.

Initially there are three regional divisions of the brain: forebrain or prosencephalon, midbrain or mesencephalon and hindbrain or rhombencephalon (Fig. 18). By 6 weeks further division of the forebrain and hindbrain result in a five-vesicle stage, the components being the telencephalon, diencephalon, mesencephalon, metencephalon, and myelencephalon, which remain as the major regions of the adult brain.[45]

The myelencephalon becomes the medulla oblongata of the adult, and its central dilatation, with that of the metencephalon, forms the fourth ventricle. Within the substance of the myelencephalon are the nuclei of the sixth to twelfth cranial nerves.

In the metencephalon are found the nuclei of the fifth cranial nerves. It is interesting that the first of the suprasegmental structures to assume

recognizable form is the vestibular apparatus of the hindbrain, the flocculonodular lobe of the cerebellum. The pons, which is composed largely of fibers leading to the cerebellar hemispheres, appears late in phylogeny and reaches its height of development only in primates. Such fiber paths appear relatively late in the embryo.

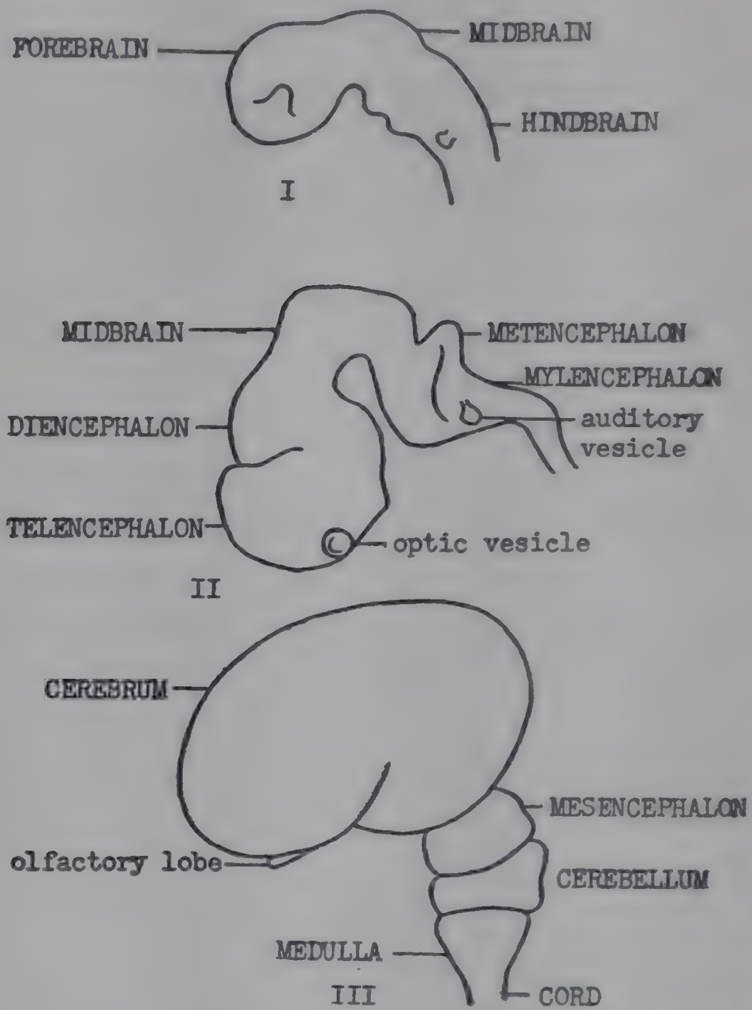

Fig. 18.—Development of the fetal brain. *I,* at 3 weeks, three regions of the cephalic prominence can be made out. *II,* at 7 weeks, further division has taken place and the five major areas of the human brain are present. *III,* by 11 weeks of gestation, the brain has taken on more definitive form. (After Patten, B. M.: *Human Embryology* [Philadelphia: Blakiston Company, 1946].)

Phylogenetically the mesencephalon is farther advanced than the metencephalon. Three major regions develop in this portion of the brain. In the roof are found the corpora quadrigemina which are the correlation centers for visual and somatic impulses and visual and auditory impulses. Connections with the cerebral cortex are also present. The middle portion

of the mesencephalon gives rise to the third and fourth cranial nerves and the red nucleus. This last structure serves as a relay station for impulses from the cerebellum to both upper (cortical) and lower neuron centers. Late in development in phylogeny is the substantia nigra, which is related to descending tracts from the cerebral cortex. Neither medullation of the tracts nor pigmentation (from which the area derives its name) is completed until after birth, the melanin deposits not being complete until about puberty.[45]

In the walls of the diencephalon are found important aggregations of cell bodies known collectively as the thalamus. Proprioceptive impulses—deep pressure, temperature and pain—are projected to the thalamus. Auditory and visual pathways enter the thalamus also and all are in turn relayed to the cerebral cortex. In addition, important centers of visceral control (body temperature, heart rate, etc.) are found in this area and are mediated through the autonomic nervous system.

The vesicles of the telencephalon become the lateral ventricles with the connecting foramina of Monro and the small third ventricle. Phylogenetically and ontogenetically the cerebral cortex is the last to appear and the last to mature. In the ventrolateral walls of the telencephalon the corpus striatum forms which contains the basal ganglions. Its connections are most complex and it is primarily concerned in the co-ordination of fine and intricate muscular activities. Superimposed on neuron chains in the more stereotyped reactions are mechanisms affording a wide choice of behavior in response to stimuli entering over the various afferent pathways. The centers for these most plastic and highest responses are found in the cortex. It is not until the seventh fetal month that the six cell layers of the cerebral cortex are completely differentiated. At birth the cortex is approximately one-half as thick as it is in the adult brain.[17, 45]

Externally certain typical landmarks begin to make their appearance by the third or fourth fetal month. At this time the sylvian fissure is recognizable. During the fifth and six months the central, parieto-occipital and calcarine fissures become apparent. All of the primary fissures, or sulci, are present by the eighth intrauterine month, but secondary folds continue to appear for several months after birth.[26, 45]

Postnatal growth of the brain is characterized by its rapidity during infancy and early childhood, a much more gradual increment during the middle and late years of the first decade, and a very small terminal increase throughout adolescence. It is not unusual to find the average brain weight

in children of 10 years of age as great as that of adults. Nearly half the postnatal growth of the brain has been accomplished by the end of the first year, three-fourths by 3 years and nine-tenths by the seventh year[57] (see Fig. 23, p. 174, and Table 25, p. 175). The postnatal growth of the cerebral hemispheres is due mainly to an increase in white matter.

The cerebrum shows a gain in weight until the later part of intrauterine existence and a slight decline in rate of growth thereafter through the first decade. The cerebellum shows a distinct increase in weight throughout the first 10 years. The brain stem is relatively large in the young fetus, declines in proportionate size until the end of the first year, then shows a small relative gain. There are no marked changes in the relative proportions of these parts after the tenth year. The relative weight of the entire central nervous system is high in early life, being one-fourth the total body weight in the second fetal month and one-tenth at birth. At about age 5 it comprises one-twentieth the total weight and at full maturity averages one-fiftieth.[45, 50]

Myelinization begins by the fourth fetal month and appears first in the tracts that are oldest phylogenetically (ventral and dorsal spinal roots). Corticospinal and tectospinal tracts do not acquire myelin, on the average, until shortly after birth. Last to receive this investment are the correlation fibers of higher centers, e.g., cerebral cortex and thalamus. Some tracts are not completely myelinated until several years after birth, and even after being completely covered, growth in thickness of the sheath continues for many years. Myelinization in the cord follows a cephalocaudal direction.‡

As the vertebral column is formed, the neural arches grow and enclose the spinal cord in the neural canal. Up to about the third fetal month the neural canal and the spinal cord are coextensive and the segmentally arranged nerves pass outward through the intervertebral spaces directly opposite their point of origin. After this period, differential growth is such that neither the vertebral column nor the neural tube keeps pace with the expansion of the posterior part of the body and the spinal cord lags farther behind than does the vertebral column. Since the cephalic portion of the nervous system is fixed in the developing cranial vault, the effect of this differential growth is to pull the cord cephalad within the canal. The spinal nerves appear to be dragged caudally from the cord and pass

‡The sequence in which the function of the various structures develops undoubtedly corresponds to the sequence in which they become myelinated; however, some function is possible in the absence of myelin.

backward through the neural canal until they enter the intervertebral space which was originally opposite their point of origin. The extent of this displacement is progressively greater in the more caudal regions. In the newborn infant the spinal cord, except for the vestigial filum terminale, ends at the upper border of the third lumbar vertebra, or about one or two vertebral levels below that found in the adult. It is therefore apparent that the differential growth continues until maturity. The cord doubles its weight in the first six months after birth, quadruples in weight in five years and has increased eightfold by the time adult life is reached.[45, 57]

The choroid plexuses are well formed early in embryonic life and cerebrospinal fluid is present. From chemical studies of the blood and cerebrospinal fluid in animals and man it has been postulated that during the first half of intrauterine life the fluid is an ultrafiltrate of the blood and thereafter assumes gradually the character of a secretion. It is probable that the blood-brain barrier is more permeable during the first few months of life than later.[62] The amount of cerebrospinal fluid in the newborn infant has been estimated to range from 30 to 60 cc.; in the child of 10 years the upper limit has been estimated at 200 cc. The cerebrospinal fluid protein content and white cell count (lymphocytes) are considerably higher in the neonatal period than in later life. The fluid is normally crystal clear at all ages. The reaction of the Pandy test for protein is positive in about half the fluids obtained from full term newborn infants and is positive in most premature infants for a period of several weeks or months. Quantitative values for protein range from 40 to 80 mg. per cent in the full term neonate and from 60 to 180 mg. in the premature infant. After one to several months (the longer periods pertaining to the healthy premature infant), normal protein values are 20–40 mg. per cent. Cell counts vary from 0 to 20–30 per cu. mm. in the neonatal period. Red cells are rarely found in normal cerebrospinal fluid in the absence of hemorrhage or improper technic of the spinal puncture. Sugar levels are higher in the newborn period than subsequently, and may nearly equal blood levels. Xanthochromia is also frequently present at this time and roughly parallels in intensity the serum bilirubin level. It is important to recognize these findings as normal during the neonatal period and not to interpret them as being always indicative of birth injury. Furthermore, the cerebrospinal fluid may be normal even when intracranial birth injury has been incurred.[§]

§The most extensive review of this important subject is that by Otila.[44]

SENSORY DEVELOPMENT

Motor function precedes sensibility, as shown by the response of the embryo to direct stimulation of muscle. Conel[17] has stated that there is evidence that the motor cortex matures earlier than the special sensory areas.

Tactile sensation.—With growth more receptors are found in the skin over a wider area and in closer proximity. In early prenatal life the first response to touch is elicited in the region of the face, more particularly the lips. Later, responses may follow tactile stimulation of the limbs and finally of the trunk in a cephalocaudal progression. However, even at full term touch and pain are not well differentiated.[12, 16]

The response to painful stimuli (pinprick) follows a fairly definite pattern of development. During the newborn period the stimulus must be strong to cause any response. This hypesthesia lasts about a week. The most characteristic response is immediate, diffuse, with general body movements and crying and possibly reflex withdrawal of the stimulated member. At 1 or 2 months of age the response is more delayed, there is a diminution of the diffuse body movements and reflex withdrawal is less common. When the child reaches 7–9 months there results a generalized localization of the point of irritation. Deliberate withdrawal movements occur which are directed away from the stimulus. Gradually the infant's ability to localize the point of irritation becomes more specific. By 12–16 months the response is one of carrying the hand directly to the point, rubbing the area or pushing the stimulus away, and the eyes will fix on the area if this is possible. This last development shows the beginning of cortical participation in behavior of this type.[37]

Proprioceptive receptors are fairly well developed by midfetal life. Stretching, tapping and causing a change in amniotic fluid pressure will elicit a response in the fetus.[62] These responses carry through into postnatal life and gradually come under the influence of higher centers.

Visual sensation.—Visual function is imperfect at birth but improves with structural and functional development of the mechanism. The visual cortex of the occipital lobe begins to differentiate at birth. At 16 weeks of age the macula and fovea complete their structural differentiation, and shortly before this myelinization of the visual fibers is completed.[40]

The light sense is one of the most primitive of all visual functions and is a mechanism of the rods and visual purple. The portion of the retina with the greatest number of rods is fully developed by the seventh fetal

month. The pupillary response is present in late fetal life. Even the smallest prematures apparently have some ability to differentiate light and dark.

Color perception is a function of the cones, which are in greatest number in the macula lutea. By means of grasp and reward methods of testing, it is believed that color perception for red, yellow, green and blue are present at from 3 to 5 months of age. It is difficult to rule out the factor of brightness in all such tests.

The eye is small and therefore hyperopic in the newborn and throughout infancy. However, because the lens is very soft and pliable, accommodation is easily obtained and allows for rapid focusing, and in this respect at least the child should have normal vision. The eyeball reaches adult size at 12–14 years of age, most of the growth occurring in the posterior segment. Ability to fixate comes with early development of the macula, and the child can accomplish this within a few weeks after birth. By 8 months, development of this structure renders the eye capable of seeing details. Final development of the macula is reached at about 6 years.

Depth sense (visual stereognosis) requires the co-ordinated use of the two eyes and the fusion faculty of the brain. Fusion is not present at birth and does not appear until central vision is established. Depth sense is developed as the visual acuity grows sharper, as the ocular muscles become co-ordinated and as the brain learns to fuse images. It is stated that fusion occurs by the sixth year.[40, 57]

After a few weeks of life the infant will fixate and respond to objects in the near visual range. By 4–5 months a visual-motor stage is reached and the infant makes approaching movements with the upper extremities. Such development proves the establishment of connections between the visual and the neuromuscular mechanism. Not until the eighth to ninth month is a deliberate reaching, prehensile stage reached. It is not until 3 years that the child can look away from the object before completion of the neuromuscular activity and the digits begin to extend just before they reach the object to be grasped. The child now is able to appraise the location and size of the object without undue effort. Such behavior displays the advancing maturation of cortical areas and their influence on the visual mechanism.

Further evidence of associations between sight and higher centers is shown by the baby at about 3 months when he recognizes familiar objects such as his bottle. By this time also the movements of the eyes are fairly well co-ordinated. At 5 or 6 months visual impulses are retained (memory)

so that there is an increasing recognition of familiar objects and faces and the response of fear to an unfamiliar face appears.[37]

Auditory sensation.—The development of the membranous labyrinth occurs early. Its essential gross parts are well defined by the second month of fetal life. Ossification of the periotic capsule begins in the fifth month. At birth, the bony investment is complete and there is little if any change in the internal ear thereafter; but later additions increase the size of the petrous bone, tending to bury the labyrinth more deeply. In general, defects of bone or sense organs are more common in the cochlea than in the labyrinth.

The internal ear takes up sensations and passes them to the brain for elaboration and appreciation. The middle ear, concerned with the collecting and transmitting of sound waves to the internal ear, is practically of adult size at birth, although the drum membrane may be smaller and more oblique. The external canal is wholly cartilaginous at birth and much shorter than in the adult. The eustachian tube is shorter and more horizontal at birth. Its shortness, like that of the external auditory canal, is due to the slight development of its bony portion as compared with the cartilaginous.[50]

Hearing, as manifested by an overt response to loud noise, is present in the full term and premature infant as soon as amniotic fluid and débris drain from the middle ear. This sense becomes acute within a few days. The infant can localize the direction of sound at 6 months and can differentiate familiar voices by the same time.

Taste sensation.—Taste is present at birth, but it is doubtful that there is differentiation of sour, salt and bitter. By 2 or 3 months of age taste is acute, and the infant will notice a change in the amount of carbohydrate in his formula or a change in milk mixtures and demonstrate by evident displeasure certain substances which are disagreeable to his sense of taste. It is natural for the infant to explore his environment by this method until his other senses, particularly tactile, are better developed. Mouthing of toys is the usual pattern until late in the first year when, except for thumb-sucking, handling and visual inspection become the more common pattern of approach.[37, 48]

Olfactory sensation.—In the premature and term infant observers have obtained evidence of olfactory function. However, it is poorly developed in early infancy and becomes more acute with advancing age.[48]

Disturbances of the special senses.—These are usually reflected in the

total behavior pattern (see Chapter 6). The two senses most commonly affected are sight and hearing. Absence of protective blinking to a strong light, absence of the pupillary reflex and failure to follow moving objects with appropriate eye and head movements constitute sufficient evidence of partial or complete blindness. Strabismus of the nonparalytic type may grow out of a deficiency in the sensorimotor or fusion requirements or may arise from reduced visual acuity in the deviating eye.

The deaf infant may show few signs of his defect for several months. A decrease in vocalization is one of the first changes noted, and accompanying this may be diminished laughter and smiling. What vocalization is present is often monotonal and unmodulated. Extreme visual attentiveness may be a suggestive symptom. Loss of contact with his environment affects the entire behavioral development of the deaf child and threatens his personality more than his intellect. As a result, "behavior problems" arise which may go unrecognized for some time before the true nature of the cause is realized.

DEVELOPMENT OF REFLEX BEHAVIOR

The fetus exhibits reflex movement of a very crude order as early as 8 or 9 weeks. These consist of flexion of the trunk, retraction of the head and retraction or backward movement of the upper arms. By 14–16 weeks the fetus is quite active, showing elementary movements of short excursion involving the extremities as well as the trunk and neck. Lip and tongue movements occur, as do swallowing efforts. Foot movements include flexion and extension of the ankle and dorsiflexion of the great toe and fanning of the other toes in a Babinski-like action.[26]

One of the earliest reflex patterns to crystallize is that of sucking. In the fourth month of fetal development the lips, which have shown motion for several weeks, begin to protrude in unmistakable preparation for the all-important reflex of sucking.[12]

At birth Chvostek's sign—a contraction of the muscles of one side of the face when the area in front of the ear of the same side is tapped with the forefinger—is easily elicited. It is not a sign of abnormal muscle irritability, hence has not the value in diagnosis of tetany that it has after the first few months of life. Similarly, Babinski's reflex can be elicited by stroking of the lateral area of the sole. For the first 12–18 months of life a Babinski reflex does not mean upper motor neuron lesion, being rather a sign of nervous system immaturity.[26, 48]

When the newborn infant is placed on his abdomen he can raise his head "turtle-like" for several seconds. At 3–4 months he dorsiflexes his head markedly when prone, and combines this with thrusts of his arms which raise the forepart of the trunk from the surface on which he is lying. When he reaches this stage he is about ready to turn himself over by his own efforts.

Numerous other reflex actions are carried on by the very young infant. He sneezes frequently, apparently in response to stimulation by light or by material in the nose. The cough reflex is also present from birth. He has an excellent eye-closing reflex at birth, as witnessed by his objections to having his eyes inspected, having drops put into them or being exposed to bright light. If the palm of the newborn infant's hand is stimulated he will grasp strongly.[26, 48]

The tonic neck reflex of Magnus-deKleign.—By the twentieth week of gestation the beginnings of this reflex can be recognized in the coordination of head and arm movements.[13] When the fetus turns his head to one side the arm on that side tends to abduct and the opposite arm to adduct. The prematurely born and the term infant lies supine with the head turned to one side, often the right. That he strongly prefers this head posture becomes evident when his head is forcibly righted to the neutral position—he quickly turns it back to the right. When the head is turned forcibly from the side of preference to the opposite side he extends both the arm and the leg of the side to which the head is now turned, and he flexes the opposite arm and leg. Sometimes the leg of the faced side flexes instead of extends. This reflex persists for three to six months after birth.[12, 13] Magnus pointed out that in lower forms there is a decided advantage to having the foot or hand extend when the head turns quickly to one side while at the same time the opposite foot flexes ready to take a step in either pursuit or flight.

The Moro reflex.—The newborn infant responds to handling, particularly if this entails sudden change in position or jarring, by the startle or Moro reflex. Typically the infant tenses all his muscles and executes a wide embrace action with his arms. The arms are extended widely and with a jerking, cogwheel action come together in a manner to embrace or seize. A counterpart of the reaction can be seen in very useful form when young monkeys cling to their mothers to be carried to safety in the time of apparent danger. The Moro reflex is increasingly difficult to elicit after 6

or 8 weeks of age, and its persistence in a child of several months usually indicates failure of normal mental development.[48]

Labyrinthine righting reflex.—This reflex can be demonstrated from the third or fourth month and persists thereafter. For this purpose the subject's eyes are covered and the body is held in different positions. The head rotates to maintain an upright position regardless of how the body is tilted.[26]

The abdominal reflexes.—These may or may not be elicited in the newborn infant but are normally present between the sixth month and the end of the first year. Their absence indicates a lesion of the descending motor pathways in the spinal cord.

The tendon reflexes.—These are present in the newborn but may be difficult to elicit owing to failure of relaxation. Crying, which is accompanied by an increasing muscle tone, will cause exaggeration of these reflexes. Occasionally ankle clonus can be demonstrated in early infancy in perfectly normal subjects.

CIRCULATORY SYSTEM

Growth of the heart in weight is characterized by a very slow increment in the first four months of gestation and a steady, more rapid increment thereafter. Then for four to six weeks after birth there is little change in heart size. After this period the heart grows steadily. During the first

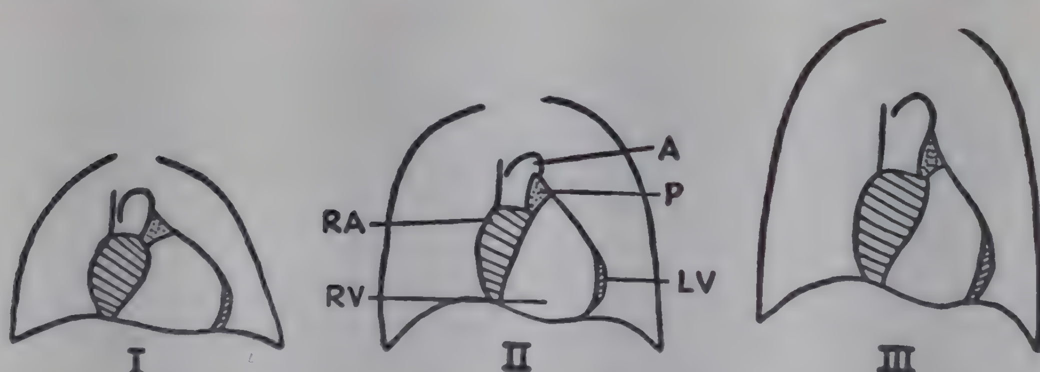

Fig. 19.—The cardiac shadow at different ages as seen by roentgenography in the anteroposterior position. *I*, early infancy; *II*, 4 year old child; *III*, adult. *RA*, right auricle; *RV*, right ventricle; *A*, aorta; *P*, pulmonary conus; *LV*, left ventricle.

year its weight is doubled; by 5 years it is increased fourfold and by 9 years, sixfold. From 9 to 16 years there is a second period of rapid growth concomitant with the increased general growth of this period.

In the full term infant the heart lies midway between the crown of the

head and the buttocks, and the axis is more nearly transverse than in later life. As in the adult, the greater part of the anterior surface of the heart is formed by the right auricle and ventricle. Except for the transverse axis and the absence of the shadow of the aortic knob, the roentgenologic picture of the heart does not differ greatly from the outline of the adult's.[54] By the end of the second or third year practically no differences exist between adult and childhood cardiac shadows (Fig. 19).

All of the components found in the adult *electrocardiogram* are also

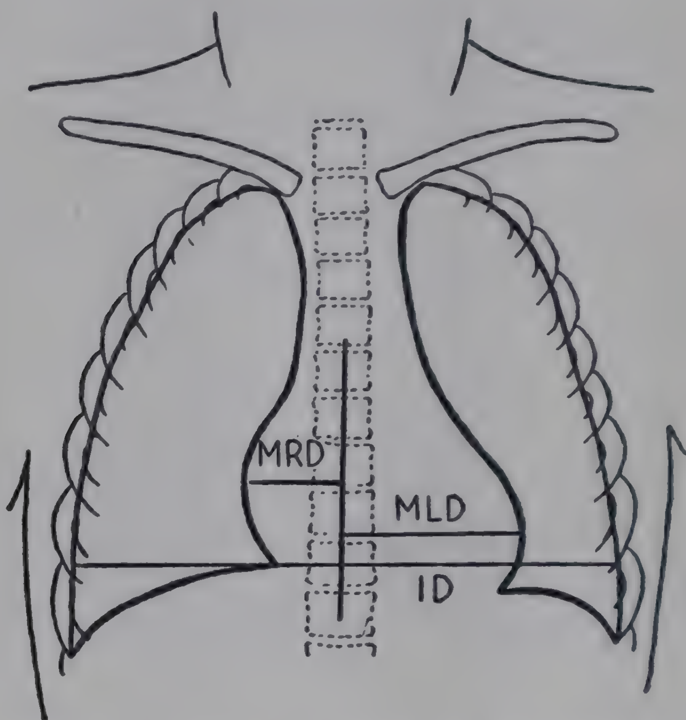

FIG. 20.—Cardiac roentgenology: method for obtaining measurements of the cardiothoracic index from a teleroentgenogram. See text for details. (From Caffey, J.: *Pediatric X-Ray Diagnosis* [2d ed.; Chicago: Year Book Publishers, Inc., 1950].)

found in the electrocardiogram of the fetus from the age of about 5 fetal weeks.[62] However, during the first few months after birth there is a tendency to right axis deviation. The smaller the heart and the more rapid the rate, the shorter will be the P-R interval. In infants the normal range is from 0.125 to 0.16 second. Below 10 years of age a normal P-R interval does not exceed 0.18 second.[23, 31, 51]

The *size of the heart* is best determined by use of the cardiothoracic index[14] (Fig. 20). This is obtained from a teleroentgenogram made by placing the patient upright in a full frontal plane with the anterior chest wall against the x-ray film cassette. The exposure is made midway between

inspiration and expiration. Tube-film distance is 72 in. The cardiothoracic index equals the total diameter of the heart *(MRD+MLD)* divided by the internal diameter of the chest at the level of the dome of the diaphragm *(ID)*. During the first three years of life the index may be above 0.5 (0.62–0.40), but after this the index of a normal child will be less than 0.5.[5] When cardiac size is measured by this method care must be taken in interpreting the result, for different phases of respiration from the peak of inspiration to the peak of expiration may change the index by a value exceeding 0.2.

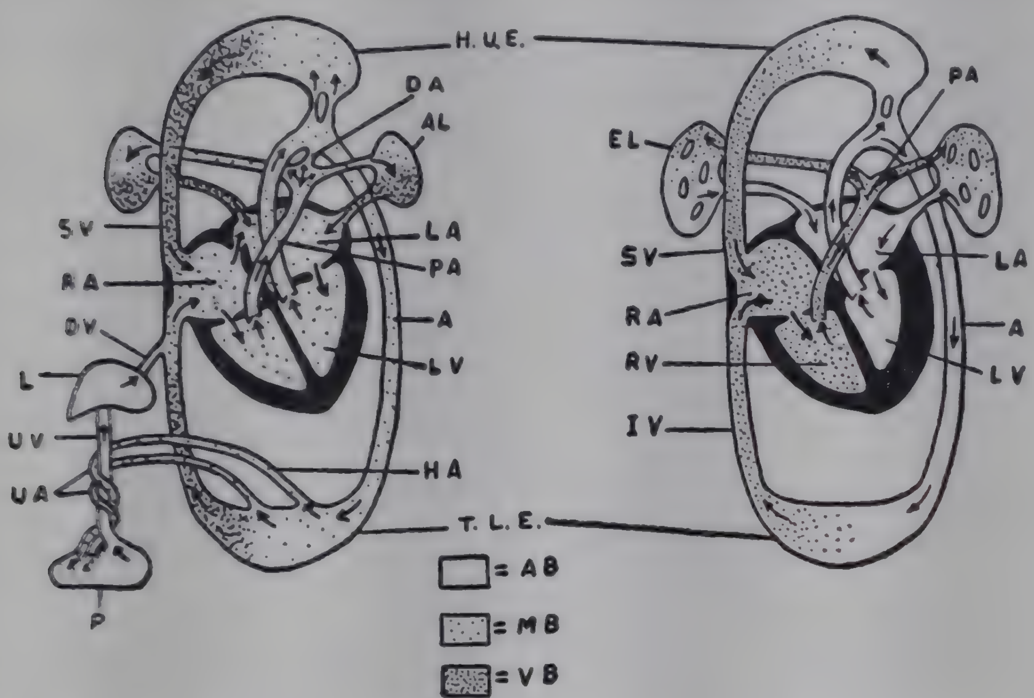

FIG. 21.—The circulation before and after birth. *Left,* fetal circulation; *right,* normal postpartum circulation. *A,* aorta; *AL,* atelectatic fetal lung; *DA,* ductus arteriosus; *DV,* ductus venosus; *EL,* expanded lung; *HA,* hypogastric artery; *HUE,* head and upper extremities; *IV,* inferior vena cava; *L,* liver; *LA,* left auricle; *LV,* left ventricle; *P,* placenta; *PA,* pulmonary artery; *RA,* right auricle; *RV,* right ventricle; *SV,* superior vena cava; *TLE,* trunk and lower extremities; *UA,* umbilical arteries; *UV,* umbilical vein. The foramen ovale between the auricles in the fetal circulation is not labeled. Arrows indicate direction of blood flow. The degree of oxygen saturation of the blood is indicated according to the key: *AB,* arterial; *MB,* mixed; *VB,* venous blood.

Position of the patient may also influence the result. Therefore a standard technic must be rigidly adhered to.[14]

The growth in caliber of *arteries* seems related to the volumes or weights of the regions they supply. In the fetus, the vessels springing from the main trunk grow in direct proportion to the parts of the body they supply, and those to the placenta grow in proportion to the vascular bed.

After birth, the trunks to the placenta become fibrotic and close completely in two to five days. These changes in fetal circulation also affect the arch of the aorta. Before birth, blood passes to the arch of the aorta from the heart and through the ascending aorta and the ductus arteriosus. Secondary to the closure of the ductus, the ascending aorta grows rapidly, and this growth during early infancy is one of the most striking changes in chest structure in this period (Fig. 21).

The thickness of the walls of the *great veins* is doubled between birth and puberty and increases by two and a half times by early maturity. The growth of the venous trunks, like that of the arterial trunks, tends to follow the increment of the parts they supply.[50]

The volume of fetal *pulmonary circulation* is greater than we formerly thought, and it is believed that there is pulmonary flow before birth since pulmonary circulation is able to support life as soon as the lungs are ventilated. After birth, under the stimulus of functional activity of the lungs, the pulmonary circulation rapidly gains in power and volume.[52] By the end of the third or fourth postnatal week the pulmonary return to the left atrium has reached approximate equivalence with the right atrial return. When this occurs, the foramen ovale falls into disuse, and the establishment of the new functional balance in the heart induces changes in the relative development of right and left ventricular musculature. The left ventricular wall does not have the preponderance in the heart in the newborn that it has in the adult, and the right ventricular muscle outweighs the left by 13 per cent at birth. Three to four months after birth the left ventricular

TABLE 18.—Average Heart Rate for Infants and Children at Rest

Age	Rate
Birth	130–150
1st month	120–140
1–6 mo.	about 130
6–8 mo.	about 120
8–12 mo.	about 115
1–2 yr.	110–120
2–4 yr.	90–110
6–10 yr.	90–100
10–14 yr.	80–90

musculature has become equal to the right and by 7 years has reached its full adult degree of preponderance.[50]

The etiology of *congenital defects of the heart* has not been thoroughly investigated. It is, however, generally believed that congenital defects are developmental arrests in which growth processes have started along normal

lines but failed to progress to completion. The reverse of this may occur, with a structure growing beyond its proper proportions. Structures molded by secondary changes may become defective by reason of resorption progressing too far or insufficiently. Other structures may form out of their proper relations.[54]

The fetal *heart rate* is usually between 130 and 160 and it is extremely variable throughout early infancy. Table 18 gives average figures for infants and children at rest. It should be obvious that a valid figure for the pulse rate may be obtained only when the child is fully co-operative and is quiet and not emotionally stimulated.

Sinus arrhythmia is to be considered a physiologic phenomenon in infancy and childhood.[23] The degree of arrhythmia is somewhat less in the infant, however, than in the older child. This finding is so constant that its absence should be looked upon as suggestive of abnormality. Investigations have shown that the presence and degree of arrhythmia are considerably less in children with rheumatic or congenital heart disease than in healthy ones. Extrasystoles appear frequently in clinically healthy subjects below 14 years of age, but they are relatively more frequent in those with myocardial damage or heart disease. "Escaped heart beats" and mild degrees of sinoauricular block are not common but may be observed in otherwise healthy children. It may be concluded that sinus arrhythmia indicates good heart function, whereas in heart disease the responsible reflex mechanism is for some reason impeded, a condition expressed by regular pulse.[23, 51]

Blood pressure in a child may vary greatly from day to day, and the increase in blood pressure that occurs with age is not constant from year to year.[22, 28] In other words, each child has his or her own pattern. Many

TABLE 19.—Average Figures for Blood Pressure (in Mm. Hg)

Age, Yr.	Systolic	Diastolic
1	60	40
3	85	65
5	90	70
8	95	70
10	95	70
11–16	100–110	70–80

factors may affect this pattern, and the "normal" blood pressure may vary over a relatively wide range. To obtain blood pressures that are of any real significance in children, a cuff should be used whose width is in about the same proportion to the size of the arm as the adult cuff width is to

the size of the adult arm. A cuff that is too large has little effect on the reading, but one that is too small will cause an error in giving a high result. Differences in height and weight for age are of little consequence, according to Downing,[22] when considering normal children. Table 19 gives the average figures.

Heart sounds during infancy and childhood are of a higher pitch, shorter duration and greater intensity than during later life. The first sound is typically the louder over the entire precordium and has a muscular quality or dull characteristic in distinction to the second sound, which is sharp in quality. Until adolescence, the pulmonary second sound is regularly louder than the aortic. Functional murmurs are very common during childhood. In a series of patients studied by Epstein,[23] the incidence of murmurs in normal children was over 50 per cent at some time during an observation period of years. Many of the subjects retained the cardiac murmurs until age 14 (the age of the oldest child studied). By far the commonest type is a systolic murmur heard best at or inside the apex. This murmur may vary in character and be musical, blowing or at times harsh. From auscultation alone it is not always possible to distinguish such murmurs from pathologic or organic ones. The incidence of precordial systolic murmurs in normal infants and children increases steadily throughout the first five to seven years; after age 9 the incidence tends to decline.[23]

In the clinical examination of children there is perhaps nothing more subject to variable interpretation than heart sounds, including murmurs. Failure to recognize organic heart disease is indeed a serious error. However, just as serious is the error of alarming parents solely on the basis of a "heart murmur." Proper evaluation must be made in all cases in which disease is suspected, and this should include the past and present history, other aspects of the physical examination and laboratory data including electrocardiography and roentgenologic studies.

CIRCULATION AT DIFFERENT AGES

It is possible, although not proved, that the ventricles in early life fill more slowly and perhaps are assisted more materially by a relatively more powerful auricular contraction than in later life. Before school age (as long as the heart rate remains above 80) no interval of diastasis is present, the ventricles being in the act of either filling or discharging during the entire cardiac cycle. During school age, due to the relatively greater development of the left ventricle and the descent of the diaphragm, the

heart occupies a more vertical position. Elastic tissue capable of assisting a rapid and full relaxation in diastole has developed in connection with the musculature of both ventricles. The vagus nerve has gained a functional control over the heart, thereby progressively decreasing its rate. By the sixteenth year the heart has adopted the adult rhythm.[51, 57]

The blood volume, relative to weight, does not fluctuate greatly throughout life. In the newborn infant the volume has been estimated to be between 100 and 130 cc. per kg.[52] In the adult the volume is usually stated to range between 80 and 95 cc. per kg.[4] The higher figures for the newborn infant are found only when the cord is clamped late after delivery. (About one fourth of all fetal blood is found in the placental circuit at the end of gestation.) Using a dye method for the determinations, Brines *et al.*[11] found that the total blood volume was about 300 cc. at birth and that it doubles during the first year of life. Thereafter it increases at the same rate in both sexes until puberty, when it averages 2,500 cc. From this age until maturity (from 12–14 to 18–20 years) the volume of males increases more rapidly than that of females, and adult values were found to average about 4,200 cc. for females and 5,500 cc. for males. These workers were unable to show any simple or direct relationship between blood volume and body weight, height or surface area.

LYMPHATIC SYSTEM

The number of *lymph nodes* and amount of lymphoid tissue bear a general relationship to age, and are more numerous and larger in the child than in the adult. For example, the average weight of the individual mesenteric lymph node increases nearly 20 times between birth and maturity while the number increases about three times.[50] Comparable figures hold for most of the lymphatic tissues throughout the body. An interesting German study cited by Scammon[50] revealed that by age 12, cervical and inguinal nodes were palpable in 100 per cent of a series of children. The number of nodes varied but averaged from seven to nine in each area mentioned. Scammon's curves of organ growth (Fig. 23, p. 174) portray the marked hypertrophy that occurs during childhood and the involution or atrophy that takes place during adult life. Tonsils and adenoids, being a part of the lymphogenous ring of Waldeyer, undergo similar changes, and one should realize that hypertrophy of these structures is a normal physiologic process.[33] The maximal development of these tissues during the time when acute infections of the respiratory and ali-

mentary tracts are most common, and during the period of greatest increase in weight and height, has led to the conclusion that they are a part of a natural defense mechanism. They may have an important part in the total pattern of immune body formation (see below). Statistical studies have been equivocal regarding the defensive value of the tonsils and adenoids, and it must be admitted that little is known concerning their function in infancy, when they may be most active as a protective mechanism.

The weight and dimensions of the *spleen* are variable at birth and throughout life. The total weight increase from birth to maturity is about twelve-fold. Unlike the other organs of the lymphatic system, it does not undergo marked atrophy during adult life.[50]

The average weight of the *thymus* at birth is between 12 and 15 Gm., but there are wide limits of normal.[8, 50] The birth weight is doubled at 6 months, tripled at 7 years, then remains constant until puberty. The observations of Boyd[8] and others[50] have proved that the lower weights mentioned in the early literature were probably based mainly on specimens which had undergone involution secondary to infection or malnutrition. Such involution may take place rapidly and a large part of the thymus weight may be lost before the body weight is seriously affected. The thymic tissue, like the lymphatic structures in general, is most abundant when the general nutrition of the individual is at its best. As a general rule, underweight and malnourished children have small thymic shadows on roentgenologic study, and overweight subjects have relatively large thymic shadows.[14] It should be emphasized that there are pronounced variations in the size of the thymic shadow in normal children. Widening of the superior mediastinum on expiration is a normal finding during infancy, and such evidence should not be misinterpreted as an "enlarged thymus." Even in later childhood the organ may have assumed a flat and wide pattern, rather than the more usual narrowing and thickening, giving the impression of a large thymus on roentgenologic examination. Figure 22 shows examples of normal thoraxes in which apparent supracardiac widening had no clinical significance.

The *function of the lymphoid tissue* is primarily one of protection of the body. There is good evidence that the formation of antibodies takes place in part or completely within this system. The phagocytic action and the filtration of noxious substances from the circulation by the lymph nodes and spleen is well recognized as an important part of the body's defensive

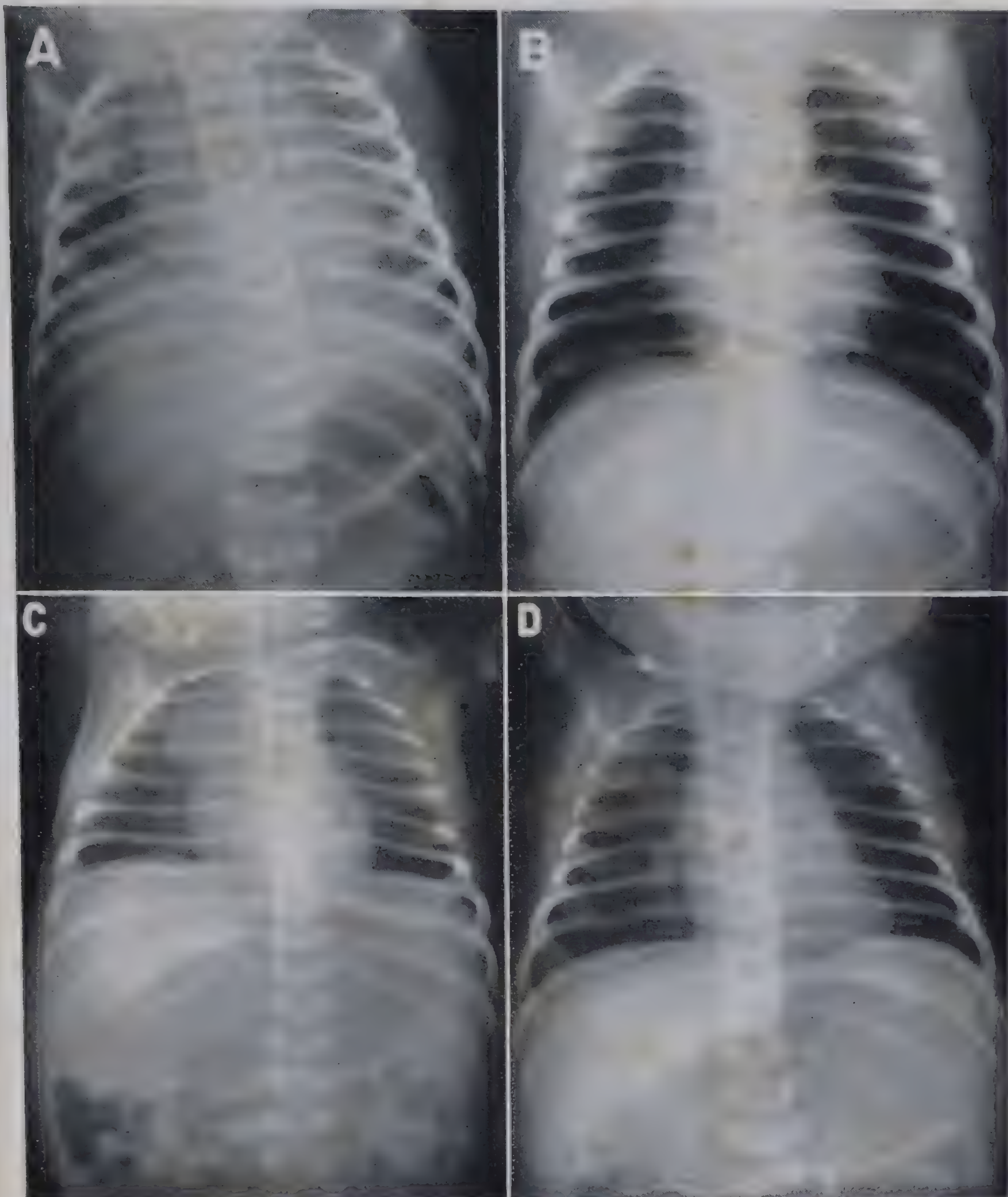

Fig. 22.—Roentgenography of the infant mediastinum. *A*, pronounced widening of mediastinal and cardiac shadows on nearly complete expiration with the diaphragms high. *B*, same infant a few seconds later, showing change in mediastinal and cardiac shadows produced by inspiration with the diaphragms low. *C*, an apparently abnormal right upper mediastinal shadow caused by improper rotation of the patient. *D*, same infant in normal anteroposterior position.

mechanism. During infancy and childhood, lymphoid tissue characteristically responds to infection by rapid and excessive swelling and hyperplasia. This hyperplasia may outlast the primary infection for relatively long periods. With advancing age such dramatic changes become less frequent. The function of the thymus remains a mystery.

HEMOPOIETIC SYSTEM

The first blood cells to appear in the embryonic circulation arise from the blood islands of the yolk sac. All of the first-formed corpuscles are nucleated, but with continued maturation they assume more and more the character of cells found after birth, and by the tenth fetal week about 90 per cent of the cells in the circulating blood are non-nucleated. In succession the blood-forming centers are found in connective tissue (mesenchyme), the parenchymatous organs, as the liver, spleen, mesonephros, and finally the bone marrow. At birth only the lymphocytes are found outside the marrow. However, the liver and spleen, and possibly other organs, retain the ability to make blood cells for some time after birth and in hemopoietic crises may again manufacture cells until early childhood is reached.[45]

In order to maintain the normal cellular equilibrium in the circulating blood, the blood-forming organs are furnished with effective reserves sufficient for all demands. At birth there is a very small reserve of cells at, or near, the stage of definitive maturation, all bone marrow showing hyperplasia of maturing cells at every stage of development. In early fetal life, the concentration of red cells and hemoglobin is low, with the red cells larger than normal and often nucleated. As the fetus grows there is a gradual rise in hemoglobin content and number of red cells, with reduction in red cell diameter and the number of nucleated forms. At the time of birth the values for red cells and hemoglobin exceed those characteristic of adult life. Shortly after birth the number of red cells and the hemoglobin content fall and reach the lowest point at about the eighth to tenth week of life. During the next two years there is a gradual rise in hemoglobin level which thereafter normally remains stationary[5, 46, 63] (Tables 20 and 21).

The blood values found during the first few days to weeks of life may be influenced by several factors.[19, 30] In babies whose cords have been clamped early after delivery the values for hemoglobin, red cells and hematocrit are significantly lower on the first and third days of life than those of babies whose cords were clamped after placental separation. For

hemoglobin, the average difference between the groups is 3 Gm., for red cell count the difference amounts to 1,000,000 cells per cu. mm. and for hematocrit 7 per cent. The reticulocyte count is higher after early cord ligation than after delayed clamping, the average being 5.9 in the former and 2.7 in the latter. In infants allowed full benefit of the placental blood the icteric index is higher on the third day than in those whose cord was clamped early. It has also been demonstrated that blood values differ

TABLE 20.—AVERAGE NORMAL BLOOD VALUES AT VARIOUS AGES*

Age	RBC, Million/ Cu. Mm.	Hgb., Gm.	WBC/ Cu. Mm.	Poly., %	Lympho., %	Mono., %	Retic., %	Plate./ Cu. Mm.
1 day	5.5	21	20,000	70	20	10	3.0	350,000
6 days	5.3	20	15,000	62	31	7	0.7	325,000
2 wk.	5.0	18	12,000	31	63	6	1.0	300,000
1 mo.	4.7	16					0.5	
2 mo.	4.0	12					1.0	
3 mo.	4.0	11					2.0	
6 mo.	4.5	11.5	10,000	32	60	6	0.8	300,000
1 yr.	4.6	12.5	10,000	38	55	6	1.0	300,000
2 yr.	4.7	13.0	10,000	45	49	6	1.0	300,000
5 yr.	4.7	13.0	8,000	54	40	6	1.0	300,000
10 yr.	4.7	13.0	8,000	60	34	6	1.0	300,000

	MCV, μ†	MCH, μμg	MCHC, %	MCD, μ
1 day	106	38	36	8.6
6 days	103	36	35	
2 wk.	96	33	34	
1 mo.	90	30	33	8.1
6 mo.	77	26	33	7.4
1 yr.	78	25	32	7.3
2 yr.	77	25	32	
5 yr.	80	27	34	7.4
10 yr.	80	27	34	7.4
Adult	87	29	34	7.5

*From Wintrobe.[63] Note that there may be a wide range within normal limits.
†MCV=mean corpuscular volume MCH=mean corpuscular hemoglobin
MCHC=mean corpuscular hemoglobin concentration MCD=mean corpuscular diameter

in the newborn with the source of the sample.[19] In general, capillary blood will give higher values for hemoglobin, red cells and hematocrit than will venous blood. A third factor to be considered is the time after birth when the blood specimen is obtained. There may be a slight rise in the red blood cell count for a day or two, but this is followed by a rather substantial drop (Table 20). All or some of these factors may account for the differences in values reported for the neonatal period. Nucleated red blood cells, not in excess of 5 per cent of the total number of nucleated cells, may be present normally for several days after birth. Macrocytosis and hyperchromia are characteristic of this period.

At about 6 years the peripheral blood picture resembles that of the adult. From Table 20 it can be seen that the early high leukocyte count of the newborn declines rapidly and that a similar phenomenon occurs with the granulocytes. From the age of 2 weeks to about age 4 years there is a preponderance of mononuclear cells in the peripheral circulation, and for another three to four years the number of these cells remains higher than in the adult.

The growing skeleton soon provides more marrow than is required

TABLE 21.—Average Values for Red Cells, Hemoglobin and Volume of Packed Red Cells in Males and Females*

Age	Red Cells, Million/Cu. Mm.	Hgb., Gm.	Vol. Packed Cells, %
10 yr.			
Male	4.7	13	38
Female	4.7	13	38
14 yr.			
Male	5.0	14	41
Female	4.7	13	39
17 yr.			
Male	5.3	15.5	45
Female	4.7	13.5	40
Adult			
Male	5.3	16	47
Female	4.7	14	42

*From Wintrobe. Note differences between male and female values after menarche.

for blood production, and fat deposits infiltrate and separate the foci of maturing blood cells so that the proportion of red to yellow marrow varies with the age of the individual. Some fat appears by the age of 7, and between 12 and 14 years there develops a definite macroscopic patch of fat in the middle of the shaft of the long bones. In the adult, only minute amounts of red marrow remain in the long bones. Red marrow is present in the ribs, vertebrae, sternum, skull and innominate bones throughout life. The proportion of the very young to the more mature forms of the maturing blood cells in the marrow is reversed with increasing age.

Cells in the circulating blood reflect accurately the marrow activity with regard to both white and red cells. Eosinophils, basophils and neutrophils arise in the marrow. Platelets arise most probably in the marrow from megakaryocytes, and their increase and decrease in the circulation are related to changes in the number of megakaryocytes. Lymphocytes arising from the various lymph nodes and spleen reflect the state of activity of the lymphoid tissue of the body. Monocytes and clasmatocytes arise from

the connective tissue and are normally present in the blood in very small numbers.

The isoagglutinogens determining blood grouping are present in the red blood cells in early fetal life, although they increase in strength during both intra- and extrauterine existence.[52, 58] The isoagglutinins also follow a rising curve, but are of relatively less importance from a clinical standpoint. The serums of some infants also have agglutinins passively acquired from the mother, and these may be of such type that they would render transfusion of blood from the mother very unwise. Finally, there is evidence that the red cells of the fetus may pass across the placenta and induce specific responses in the maternal serum. In erythroblastosis fetalis (hemolytic disease of the newborn), hemolysins induced in the mother's serum by this means may cross the placental barrier and produce severe blood destruction in the fetus.[4] The Rh factor is the best known of the specific agglutinogens of the fetus responsible for such a train of events. Because of these factors it is advisable always to type and cross-match blood before it is used for transfusion of newborn infants.[58] The old belief that the infant has not yet developed his blood group is no longer tenable.

DEVELOPMENT OF IMMUNITY

The problems of immunity are so closely linked with the study of blood that a few words concerning this subject would seem apropos. It is well known that passive immunity to some diseases exists as a result of passage of antibodies from mother to fetus.[38, 43] This immunity usually lasts from six to nine months after birth. Diphtheria, tetanus, measles, smallpox and poliomyelitis are among the diseases to which immunity is established provided the mother has had an opportunity to form antibodies against them. The antibacterial antibodies, in contrast to the antitoxic and antiviral substances, persist for shorter periods. The serum of umbilical cord blood contains antibodies with the same relative activity as those found in maternal blood.[38] The titer gradually falls after birth and becomes insignificant for antibacterial antibodies by the second month of life.

Although human colostrum contains many of the antibodies found in the maternal serum, the titer is much lower. Moreover, the activity of the infant's antibodies is little influenced by the feeding of breast or cow's milk, with the possible exception of agglutinins for some of the enteric organisms.[38, 52] This may be one of the reasons why colon bacilli are not

predominant among the common intestinal flora of the breast-fed infant.

With increasing age there is a rise in the titer of the common antibodies in the child's serum.[2] This augmentation is perhaps best explained by increasing opportunities for subclinical and clinical invasion of the body by infectious agents.[38] The active immune responses to antigenic stimuli may be less efficient in the neonatal period than later in life. However, it now seems feasible to carry out active immunization procedures against smallpox, diphtheria, pertussis and tetanus before 6 months of age since most infants do show an adequate antibody response to them by the third month. Inadequacy of antibody response in the neonatal period is probably related to low concentrations of serum (and cellular) globulins. It may be that a rise of the globulin level is stimulated by antigens, and the low concentration is a direct result of infrequent exposure to antigens during this period of life. Studies by electrophoretic methods have revealed that the gamma globulin content decreases in the first few weeks after birth to a low level.[21] The subsequent rise in all globulin fractions is very slow, and by the end of the first year adult levels have not yet been reached. Since the gamma component includes most of the antibody globulins, the results are consistent with other evidence regarding immunologic processes in infants.

Maturation of the tissues may also influence immunity. For example, reaction to the Schick test performed during the neonatal period is frequently negative although no antitoxin is found in the circulation.[18] A possible explanation for this phenomenon may be a temporary incapacity of the skin to react, but there is strong evidence that it represents a tissue immunity to diphtheria toxin. A further example of change in immunity with age is brucellosis. Infection of young children is as uncommon as infection of calves with the organism *Brucella abortus*. Apparently immature tissue will not harbor the infectious agent. Allergy, a tissue response similar to if not the same as immunity, usually affects an infant by exciting a reaction of his skin (eczema), whereas the more common response in the older subject is in different tissue, namely, the respiratory tract. Not infrequently the child with asthma has a history of infantile eczema. The increased susceptibility to tuberculosis during adolescence may be related to immunity, endocrine function, nutrition and the opportunities of increased exposure.

As final examples of the course of developing immunity one can cite the common infections encountered at certain ages and the response of the

body to them. During the newborn period septicemia is far more common than at any other age. There is little tendency to self-limitation or localization of the infection. The neonate seldom responds with striking elevation of temperature. In fact, such symptoms as anorexia, vomiting, diarrhea and subnormal body temperature are much more reliable signs of infection in this age group. During later infancy and early childhood, infections of the respiratory tract are most common, and the child of this age frequently responds rather violently with hyperpyrexia, convulsions and gastrointestinal upsets. Evidence of a growing immunity is exemplified by the rarity of serious infections with *Hemophilus influenzae* in children past 3 or 4 years of age. During the school years the various exanthems make their appearance, and the complications of infections, such as nephritis and rheumatic fever, come into prominence. It is of considerable interest and importance to note that neither of these complications is at all common during the first few years of life. Hyperpyrexia and convulsions are less frequent in the school-age child than in the preschool child. The association of tuberculosis with adolescence has been mentioned. It becomes apparent that age influences the body's immunity and the reaction of specific tissues to disease processes.

NORMAL CONSTITUENTS OF BLOOD

Besides the formed elements, the blood contains many substances in solution or in the form of colloids. The blood content of many of them reflects in a large measure the workings of organs or organ systems, especially the kidneys, lungs and liver. Table 22 shows the trends of the various constituents with change in age or maturation. It must be emphasized that each laboratory has its own procedures and consequently its own normal values which may differ slightly from those given. Furthermore, for some age groups and for some substances the number of determinations has been quite small. Most of the estimations were made on capillary blood. This has been done because such methods are becoming increasingly popular in hospitals and laboratories where large numbers of children are examined, because much smaller quantities of blood are necessary, making such procedures more practical, and, finally, because we are more familiar with these micromethods. The estimations for total lipids, cholesterol, phosphorus and phosphatase still depend on macromethods.

We are becoming increasingly aware of the individual differences in normal or average blood chemistry values and of a surprisingly wide

range of values for many constituents. Particularly during the neonatal periods of both the full term infant and the prematurely born infant the ranges are wide and the fluctuations within the individual are great. When it is realized that this is a period of great instability for all of the physiologic mechanisms of the organism, such findings need not confuse. The time of day, number of days after birth and ingestion of food may also affect the values obtained. As examples, we know that during the first few days after birth blood calcium levels, glucose levels and the quantitative prothrombin time are all reduced but reach higher levels in a short time. The phosphorus value, on the other hand, remains relatively elevated in many cases for weeks or months after delivery. The reasons for such changes are not always clear, but the interpretation of seemingly abnormal values from a clinical standpoint must be made with caution in the light of these observations.

TABLE 22.—NORMAL VALUES FOR CONSTITUENTS OF BLOOD*

SUBSTANCE	PREMATURE	NEONATE	INFANT	5–15 YR.
Urea N, mg. %	(20–47)	19 (10–30)	(6–20)	(6–15)
NPN, mg. %	(24–63)	45 (25–62)	35 (25–45)	(25–35)
Uric acid, mg. %	3.25	3.5 (2.7–5.1)	3.0	3.0
Serum protein, Gm. %	5.6 (4.5–6.0)	6.1 (5.0–6.9)	6.5	(6.5–8.0)
Albumin	4.2	4.5	4.7	5.0
Globulin	1.4	1.6	1.8	2.0
Glucose (fasting), mg. %	(27–90)	(47–102)	(70–120)	(70–120)
Total lipids, mg. %	...	221	470	(500–700)
Cholesterol, mg. %	(75–200)	(100–200)	(100–225)	(100–260)
Electrolytes, mEq./l.				
Total base	159 (152–171)	153 (148–160)	152	152
Sodium	(138–159)	144	144	144
Potassium	...	7.8	6.0	6.0
Chloride	(104–120)	(102–110)	(100–107)	(100–107)
Bicarbonate	(12.7–25.3)	(18–27)	(23–28)	(23–28)
Serum calcium, mg. %	11.0 (8.7–12)	(8.6–13)	(10–12)	(10–12)
Serum phosphorus, mg. %	(6.0–8.5)	(5.5–7.0)	5.0	5.0
Phosphatase, Bodansky units	...	(7–10)	(9–15)	(5–13)
Serum bilirubin, mg. %	(1.5–7.5)	(1.4–6.0)	(0.2–0.8)	(0.2–0.8)
Lactic acid, mg. %	(15–30)	17	10	10

*Average figures are given as a single value; the range is enclosed in parentheses. Data from various sources and the Pediatric Laboratory, University of Michigan.

During infancy there is an increasing tendency toward stabilization in the healthy subject. After the first year of life the child has become

relatively homeostatic so far as most organ functions are concerned. Throughout this chapter we have discussed the relations of organ functions to age and to a limited extent have drawn attention to the blood levels of various substances. Reference should be made to these sections as well as to Chapter 11 for further examples of blood chemistry and interpretation.

DIGESTIVE SYSTEM

Some aspects of the embryologic development of the gastrointestinal tract are important to an understanding of various congenital anomalies.[45] During the fifth and subsequent fetal weeks there is a conspicuous elongation of the gut which results in a long loop extending ventrally into the belly stalk (the future umbilicus). At the end of this loop is found the yolk sac, which forms a valuable reference point for orientation in following the rotations of the lower intestinal tract. When the gut tract is viewed in ventral aspect, a counterclockwise twisting of the loop is seen. This initial rotation is the primary factor in establishing the positional relations of the large and small intestine. Referring to the yolk sac, that portion of the gut caudal to its attachment becomes the large intestine and a small portion of the distal ileum, while that portion cephalically located becomes the duodenum, jejunum and the remainder of the ileum. By the tenth fetal week the abdominal cavity becomes large enough to accommodate the intestines, and at this time the cecum is found in the left upper quadrant. Rotation continues so that the cecum normally passes over the duodenum first to the right upper quadrant and finally descends to its usual position in the right lower quadrant. Descent is not completed until some time after birth. With this rotation is carried the mesentery and the distal portion of the ileum.

If growth of the abdominal cavity is disturbed to the point that it cannot hold all of the mass of the intestines, they may remain protruding into the belly stalk as an umbilical hernia or, if protruded to a severe degree, as an omphalocele. With persistence of the yolk stalk the anomaly of Meckel's diverticulum occurs. This may take several forms. It may remain attached to the abdominal wall as a fibrous cord or may remain patent so that the contents of the ileum have a fistulous opening at the umbilicus. Finally it may be a simple sacculation of the ileum. Not infrequently the lining of these diverticula contains mucosa typical of gastric mucosa, leading to ulcer formation.

Incomplete rotation of the gut is not uncommon, and the cecum and adjacent structures may be found in adult life at any position along the path normally followed. Malrotation results from a reversed twisting of the primary gut loop and the small intestine lies ventral to the transverse colon instead of dorsal to it. Such a developmental anomaly causes volvulus in a high percentage of cases; it may be present at birth or not occur until a later age.

Toward the end of the second fetal month the epithelial lining of the gut tends to grow so exuberantly that complete occlusion results. Such changes are particularly apt to take place in the esophagus, upper part of the small intestine and in the rectum.[45] If for some reason the lumen is not re-established, congenital atresia results. If recanalization is partial, stenosis occurs. Bremer[9] has hypothesized that if two epithelial lumens are formed rather than one, and if this condition persists, duplicate tubes are formed, resulting in the curious anomaly of reduplication of the gut, for example, ileum duplex.

The position of the esophagus in the newborn is the same as in the adult except for its relation to the vertebral column, being one vertebral level higher, with the superior limit at the fourth or fifth cervical vertebra and inferior limit at the ninth thoracic vertebra. At birth it is lined with stratified squamous epithelium five to six cell layers thick. Ciliated cells appear between 12 and 16 weeks of fetal life as a transient condition. Esophageal glands are present at birth but become more complex during later life.[50]

Embryologically, the stomach has the subdivisions and form found in the adult. In the infant, the stomach lies with its long axis in the transverse plane of the body. In the second to third year, the "cow's horn" form is most frequent. By the seventh to ninth year the "fish hook" type is seen, and from 10 to 12 years onward the stomach is similar to that of an adult.[57] Growth of the stomach is most rapid between birth and the third month of life. At other times the increase in mucosal area is slow and even. Most of the figures in the literature on the capacity of the stomach at various ages are based on postmortem studies and are therefore fallacious. The capacity is fixed only by the maximal limits of distention and varies widely with the size of the infant, the amount of ingested material and the amount of swallowed air. Very rough approximations are 30–90 cc. at birth, 90–150 cc. at 1 month and 210–360 at 1 year. By age 2,

capacity is 500 cc., and in later childhood the average capacity is between 750 and 900 cc.

The length of the small intestine in the newborn varies from 300 to 350 cm., increases about 50 per cent in the first postnatal year and is doubled by puberty. The annular type of duodenum is the form most commonly found in the newborn and young infant.[57] The cecum of the infant is much smaller than that of the adult. The appendix is relatively the same length at birth as later, but it grows rapidly during the first year. The ascending colon is relatively shorter in the newborn than in the adult; the transverse colon is relatively long and may be thrown into folds. The sigmoid colon is usually filled with meconium and is thrown far upward in the abdominal cavity, but it regains its usual position a year after birth. The rectum is relatively longer at birth and in the child than in the adult.[10]

The salivary glands are said to increase threefold in weight during the first six months of life and fivefold in the first two years, and by this time to have acquired all the histologic characteristics of the adult.[57]

At birth, the pancreas is at the level of the second or third lumbar vertebra. It assumes adult histologic appearance by the end of the first year. Pancreatic secretions in the newborn are quantitatively less on the basis of weight than in the adult with respect to lipase and diastase, but equal with respect to trypsin. The smaller the infant at birth the smaller the quantity of lipase present.[65]

In the newborn infant the liver occupies nearly two fifths of the abdominal cavity. The lobulated structure is poorly developed at birth, and lobulation does not become complete until after early childhood. The liver at birth forms 4 per cent of the body weight, and by puberty weighs 10 times as much. A palpable liver edge is very common throughout infancy and early childhood. The gallbladder of the infant increases in size rapidly during the first two years of life.

There is no evidence that the act of swallowing in infants differs from that in adults. The act of sucking is a pure reflex with its center in the medulla. Repeated regurgitation of gastric contents into the esophagus, however, is the rule in infancy.

Roentgenologic studies of the intestinal tract of the normal newborn infant reveal that about 24 hours elapse between the first appearance of air in the stomach and its passage to the rectum.[7, 14] The esophagus of the infant may be sinuously curved, and after the first few swallows of

barium there may be a rather pronounced retention of the material in the lower end for several minutes. Gas bubbles passing upward from the stomach frequently push the barium back, causing regurgitation.[1] In the stomach of an infant less than 3 months old there is seldom evidence of a true peristaltic wave, the stomach appearing to contract as a whole. The gastric emptying time during infancy may vary greatly, normally occurring in from two to six hours with barium mixtures.[7] Examination of the small and large intestines reveals little difference from those of the adult except for the relative high position of the cecum throughout early infancy and the redundant sigmoid, previously mentioned.[10] However, until age 4 or 5 years the colon appears disproportionately large, and megacolon has been mistakenly diagnosed in many normal children as a result of failure to recognize this characteristic. Muscular spasm in the colon is rather frequently observed and has no significance in the absence of other findings.

In the normal full term infant, saliva has been found in the mouth before food has been taken. Gastric juice is secreted by the mucous membrane of the stomach and hydrochloric acid is present before birth. There is great variation in the amount of free acid in the infant's gastric secretions, but achlorhydria is rare. There is a strikingly high output of hydrochloric acid immediately after birth.[27] There is a gradual fall in output during the next 10–15 days, followed by a rise to near adult levels by the end of the fourth month. Pepsin has been found in the gastric juice of the 4 month fetus. This enzyme increases in quantity from birth to age 4 months, after which a constant level is reached. Rennin has also been found at birth. Amylase activity in the duodenum is decreased in infancy, but in older children is the same as in adults. Lipase activity is low throughout early childhood. Trypsin activity is adequate from birth.[52]

Little is known about hepatic function in infancy and childhood. Several observations lend support to the belief that, compared to the adult liver, the infant liver is physiologically immature.[32, 49, 52, 55, 64]

1. The physiologic hyperbilirubinemia of the newborn is judged to be due to an inability of the liver to excrete bilirubin. Visible jaundice is more common in the premature than in the term infant.

2. During infancy the bile excreted is of low concentration compared to that excreted in later life.

3. The prothrombin level at birth is 20–40 per cent of the normal adult level. It slowly rises to the adult level at the end of the first year. The prothrombin time by Quick's method, which measures the time necessary

for the formation of thrombin from prothrombin, is about normal at birth and falls by the second or third day, to return to normal by the sixth day. Prothrombin is formed in the liver.‖

4. Ketone bodies are not formed by the liver of the young infant. As a rule, acetone will not be found in the urine at any time before 4 or 5 months of age.

5. The blood protein values are reduced throughout early infancy.

6. The low blood sugar levels found during the first few days of life may in part be due to lowered gluconeogenesis from protein.

7. Levulose tolerance tests are reported to show low values in the newborn.

8. Cholesterol esters are formed chiefly in the liver. The low blood level of this group of substances during the first year may reflect hepatic immaturity.

9. The ability to excrete bromsulfalein is reduced during early infancy.

At birth the intestine is filled with a substance called meconium which is somewhat viscid and dark greenish-brown to black. The normal infant passes some of it the first 10 or 12 hours and meconial characteristics disappear from the fecal mass by about the fourth day. During this period occult blood is not an abnormal finding. From the fourth to the seventh day the infant passes transitional stools which are thin, sour, slimy, brown to green and may contain remnants of meconium. The stools of the breast-fed infant are homogeneous, sour, pasty and yellow. The number of stools during early infancy varies considerably, usually numbering two to four a day for the breast-fed infant and one to three for the bottle-fed baby. As the diet becomes more varied and the relative amount of milk is diminished the fecal material becomes more formed and darker and by 2 years does not differ greatly from the adult stool.

The first meconium obtained is usually sterile, but within hours all material passed through the intestinal tract contains bacteria. These bacteria are for the most part ingested, although retrograde contamination may have a small role. The intestinal flora of the infant differs to some extent from that of the older child and adult.[52]

RESPIRATORY SYSTEM

By the sixth week of fetal life the trachea, bronchi and lung buds can be clearly differentiated and their migration toward the thoracic area has

‖Another factor to be considered is the reduced synthesis of vitamin K in the gut owing to decreased bacterial flora in the neonatal period.

begun. This migration is almost completed by the third fetal month, and thereafter the lungs descend very slowly. From its first appearance the right primary bronchus is somewhat larger than the left and is situated at a more acute angle. Although these differences become less marked with growth, they remain sufficient postnatally to account for the fact that foreign bodies more often enter the right bronchus than the left.[45]

The absolute dimensions of the larynx at birth are approximately one-third those of the adult, but relative to the rest of the body it is as large or larger than at maturity. The cavity of the larynx is short and funnel-shaped throughout infancy. During the first two or three years the growth of these structures is rapid, then there is a slower increment until puberty. At that time, particularly in males, there is again a rapid increase in all dimensions. From about the third year on, the larynx is longer and wider in boys than in girls. In the newborn the upper end of the epiglottis lies at the level of the first cervical vertebra and is easily seen during physical examination. It gradually descends so that at puberty it is opposite the lower half of the third cervical vertebra.[50]

The trachea in the newborn infant is about 4 cm. long, roughly one-third the adult length. Both diameters, anteroposterior and lateral, increase nearly 300 per cent from birth to puberty. The small lumen explains the respiratory difficulty associated with the inflammations of this organ in the young child. At birth the bifurcation of the trachea lies at the level of the third or fourth thoracic vertebra, at 4 years at the level of the fifth thoracic vertebra and at 12 years between the fifth and sixth thoracic vertebrae.[50]

The weight of the lungs of a newborn infant in which respiration has been established is not significantly greater than that of a stillborn infant.[50, 52] This would seem to show that there is no great or sudden influx of blood into the pulmonary bed with the beginning of respiration. The weight of the lungs is doubled in the first six months, tripled by age 1 year and increased 20 times by adult life. There is little change in topography of the lungs, fissures or pleura from infancy to maturity. Anteriorly there is a slow descent of the lung margin from the fifth to the sixth rib during growth.

In the premature infant several important anatomic features of the respiratory system differ from those of the mature newborn.[35, 61] There may be a conspicuously impoverished pulmonary vascular bed in the immature infant, and this may explain the impediment to gaseous diffusion

and the tendency to cyanosis. There may also be a sparsity of pulmonary elastic tissue, contributing to the persistent atelectasis in the premature infant. And finally, the feeble musculature and the soft bony thoracic cage augment the respiratory difficulties.¶ (See also p. 92.)

Many of the aspects of respiratory physiology in the fetus and newborn are still under study, and many of the facts now known are interpreted in different ways. The interested reader is referred to Smith[52] and Windle[62] for further discussion.

Much evidence has been presented that respiration-like movements take place in utero.[6, 62] Whether such movements result in a normal tidal flow of amniotic fluid is still open to question. It is known that clamping of the umbilical cord will cause fetal respiratory movements from an early stage until birth. Tactile stimulation will cause reflex movements of the thorax in the human fetus by the twelfth week of gestation.[62] The ability of the fetus to respond in this manner at an early age shows the protective mechanism afforded by Nature.

Both the fetus and the newborn have an excessive amount of hemoglobin that differs qualitatively from that found after a few weeks of extrauterine life. Both the quantitative and the qualitative characteristics allow more oxygen to be carried per unit of blood and a greater uptake of oxygen from the lungs. However, there may be a resultant lessened efficiency in the release of oxygen to the tissues. A third characteristic of neonatal blood is the relatively small amount of carbonic anhydrase. This tends to retard liberation of carbon dioxide and acquisition of oxygen in the lungs.[52, 59] The clinical importance of a low anhydrase level has yet to be completely evaluated.

The fetus and the newborn are known to be much more resistant to the harmful effects of anoxia than are adults.[52] The reason for this is not clearly understood, but it is known that in the newborn animal there are possibly three important factors: (1) low cerebral metabolism, (2) low and variable energy metabolism and body temperature, and (3) an anaerobic source of energy. Infants who have not breathed for as long as 14 minutes after birth have survived the anoxia to make apparently normal subsequent progress.

The most important stimulus to the onset of breathing is probably anoxia resulting from the interruption of the oxygen supply carried by the

¶ A relatively decreased (immature) vascularity in the respiratory center of the brain may also be responsible for a reduced sensitivity to stimuli in the smaller premature infants.[56]

umbilical vessels. Such changes result in the accumulation of acid metabolites in the respiratory centers of the medulla, and the resulting fall in the pH furnishes the true stimulus.** At the time of birth most of the alveoli are collapsed and those that are open are filled with fluid. In addition, there is a definite cohesive force of the moist surfaces of the smaller bronchi and alveoli. Wilson and his associates[59, 60] concluded that the first breath may be the most difficult and that for a variable period after birth vigorous inspirations should be maintained. Some degree of persistent primary atelectasis may be present roentgenologically for more than a week in a normal infant, and in the premature may last several weeks.[14, 60] It is believed that such atelectasis, when present, is normally slight.

With the first inspiration most of the alveoli are enlarged and the epithelium lining them is reduced from a low columnar to a flattened

TABLE 23.—VARIATIONS IN RESPIRATORY RATE AND TIDAL AIR WITH AGE*

AGE	RATE/MIN.	TIDAL AIR, CC.
Premature	40–90	12
Newborn	30–80	19
1 yr.	20–40	48
2 yr.	20–35	90
3–7 yr.	20–35	125–200
8–14 yr.	18	220–400
Adult	16	500

*Averages for quiet respiration.

squamous type. Few, if any, new alveoli are formed after birth. However, the average size increases slowly so that the diameter in fixed specimens is three to four times greater at puberty than in infancy. The elastic tissue is sparse in the newborn but increases rapidly during the first few months of life.[50, 59]

Respiration in infants is largely diaphragmatic in character and continues so until the fifth to seventh years of life, when the costal element becomes more prominent.[31, 34] The rate and depth of breathing are extremely variable in infancy, and the younger the subject the greater the possible variations. Table 23 shows the variations in respiration with changes in age.

The change in the relative measurements of the chest with age has been discussed (p. 49). The conical shape of the adult chest is not attained until near puberty.

**It is quite possible that the aortic and carotid chemoreceptors play a more important role in initiation of the stimulus to respiration than does the center in the medulla. A sufficiently prolonged period of anoxia following birth may so disturb the mechanisms involved that they cannot function properly.

Auscultation over the chest of the infant reveals that the breath sounds are loud, harsh and seem near to the ear. These characteristics are due to the fact that the tracheal and bronchial sounds are more distinct and are transmitted through less tissue than in the adult. The percussion note over the lung fields of the infant and young child is more resonant, even tympanitic, than in the older child or adult. The reasons for this are the same as for the differences on auscultation. Because even slight changes in position of the infant, such as turning the head, may influence the relative position of intrathoracic structures and therefore the intensity of the breath sounds or the degree of resonance, care must be taken in interpretation of these physical findings.

Bronchovascular shadows in roentgenograms of infants and children are often difficult to read properly. They are relatively more prominent than in the adult, and studies have shown that there is no very exact correlation between the size and density of the hilar shadows and the incidence of upper respiratory infections. There is considerable variation among children so that simple comparison has little value. Evaluation of these markings by the inexperienced has no doubt frequently led to the erroneous diagnosis of bronchitis and even bronchiectasis. It should be remembered also that shadows extending from the hilus are normally more dense in the inferior segments than above. Owing to the heart shadow, they are relatively more prominent on the right side. As in roentgenographic study of the mediastinum, the phase of respiration influences lung markings and both phases should be observed when examination is made to find pathologic conditions, especially atelectasis, emphysema and nonopaque foreign bodies.[14]

Malformations of the respiratory tract are relatively rare.[45] Agenesis of one lung or congenital cysts of the lungs may occur. Congenital laryngeal stridor may be the result of small size or abnormal proportions and of a peculiar weakness of the musculature. The most common tracheal anomaly of serious clinical significance is a tracheoesophageal fistula, frequently associated with the cephalic portion of the esophagus ending in a blind pouch.

URINARY SYSTEM AND WATER BALANCE

It is the function of the kidneys to help in regulation of the internal environment of the body. They accomplish this in the following manner:

1. Excretion of nitrogenous waste products, mainly in the form of urea.

2. Stabilization of osmotic pressure by selective excretion and reabsorption of electrolytes, sugar, etc.

3. Stabilization of chemical composition by the mechanism of "renal threshold" and selective excretion and reabsorption.

4. Regulation of extracellular fluid volume which is partly dependent on (2), also through the action of the posterior lobe of the pituitary body in regulating total fluid output.

5. Maintenance of acid-base balance by electrolyte and osmotic regulation, excretion of excessive accumulation of either acid or alkali and the formation of ammonia in the kidneys to neutralize acid and conserve base.

These actions of the kidneys are supplemented and influenced by other organs or systems, especially the following: lungs, through loss of fluid and excretion of bicarbonate; posterior lobe of the pituitary body, by regulation of water and electrolyte excretion from the kidney, and, finally, the adrenal cortex, through control of sodium, potassium and chloride metabolism.

In the discussion on fetal growth we have seen that after birth there is no pronounced change in the proportion of total body water to body weight. However, there is considerable change in the location of that fluid from birth until maturity.[24, 25] The extracellular fluid volume of the newborn infant is nearly double that of the adult, about 43 per cent of the body weight being extracellular fluid in the former and 25 per cent in the adult. (These figures are based on methods measuring the sodium space of the body, which is not strictly extracellular.) Evidence so far obtained reveals that the decrease in extracellular volume of fluid occurs mainly at two different periods of rapid growth. There is a great decrease during early infancy and a less pronounced decrease during adolescence. The intervening period is relatively constant.[24]

Not only does the infant have a greater content of extracellular fluid than the adult, but the rate at which fluids are exchanged is much greater. The average adult takes in and excretes about 2,000 cc. of water daily, representing about 5 per cent of his total body fluid or 14 per cent of his extracellular fluid. The infant's daily exchange of 600–700 cc. of water, in contrast, represents about 20 per cent of the total or nearly 50 per cent of his extracellular volume. Of the water lost, some is by surface evaporation and some through the lungs. However, the 6 month old infant on the average loses only 20 per cent as much as the adult by this means. Daily excretion of water by the gastrointestinal tract of the baby may equal

1,000 cc., of which one-half is reabsorbed and the remainder is lost in the stool. It is no surprise to learn that control of this rapid water exchange by the infant is less precise than that achieved by the older child or adult, and consequently one sees more severe dehydration in the face of illness in the less mature organism.

The composition of the body fluids also has some tendency to differ with age.[36, 42] The total electrolyte concentration in extracellular fluid tends to be slightly greater in the newborn subject than in the adult (as judged from blood analyses). There is a greater concentration of sodium, chloride, phosphates and organic acids. These differences are even more striking in the premature baby. On the other hand, the concentration of bicarbonate ions is lower in the newborn infant than in the older child and there is mild acidosis, manifested by a slightly lowered pH. These variations, plus a lowered plasma protein level, cause a reduced colloidal osmotic pressure of the vascular compartment and favor an accumulation of fluid in the tissue spaces and an increased filtration rate of the kidneys. In health, these differences between the infant and the adult do not maintain themselves beyond a few weeks or months. The premature and normal newborn infant are usually in a state of well compensated acidosis and in a state of potential or, in prematures especially, manifest edema. A study of the growth of the urinary system will aid in a better understanding of these facts.

The growth of the kidneys is slow in the early part of prenatal life and rapid in the later part. Kidney weight is doubled in the first six months after birth, trebled by age 1 year and increased five times by 5 years. By puberty the increase is 10 times that of the birth weight of these organs. Formation of the last renal tubules has been estimated to take place from the eighth month of gestation to the end of the first month of life.[52] It is probable that no new glomeruli are formed after the ninth month of gestation, but throughout fetal and neonatal life the glomerular tuft is covered by a much thicker layer of cells than at any later time.[36, 52] This anatomic feature may explain the lowered glomerular filtration rate found during the first nine months of life, in spite of the lowered osmotic pressure of the plasma. The lower blood pressure of the infant may also play a part. All of the glomeruli increase in size after birth, but the peripheral ones grow more rapidly.

At birth the kidneys occupy a large portion of the posterior abdominal wall owing to their relatively large size. Fetal lobulation persists through-

out the first year. The ureters in the infant are relatively and absolutely shorter than in the adult. In the newborn the bladder lies close to the abdominal wall, and the lower level is behind the middle of the symphysis pubis. During childhood the bladder descends into the pelvis.[50]

The physiologic growth of the kidneys seems to lag slightly behind the anatomic growth. During intrauterine life their function is largely taken over by the placenta; however, urine is secreted probably as early as the third fetal month. The kidneys function well enough for all ordinary purposes during neonatal life, but physiologic immaturity is apparent from the following observations:[15, 36, 42, 53, 56]

1. As judged by urea clearance, adult levels are not reached until late in the first year. This functional difference between the infant and adult is even more exaggerated in the premature baby.

2. The rate of glomerular filtration in the 14 day old infant is about half as efficient as in the adult as measured by inulin clearance. Adult values are not reached until near the end of the first year.

3. Renal plasma flow, based on body surface, does not reach adult levels before the seventh month.

4. The adult values for maximal tubular excretory capacity, based on body surface, are not attained for six months or longer. (It is recognized that the major growth of the kidney during the first year is due mainly to an increase of tubular tissue.)

5. Low clearances of sodium, chloride and urea (and some other but less important minerals) result in a hypotonic urine as compared to plasma during the neonatal period.

6. The ability to concentrate urine is inferior to that of the adult for some time, even when the infant is given little or no fluids.

7. Owing to a low phosphate clearance, little or no phosphate may be present in the urine of infants. Apparently as a compensatory mechanism, more ammonia is excreted to combine with the total acid found in the urine. The phosphorus-nitrogen ratio in urine in infants averages 2.92, whereas in adults it is 12.64.

8. Albumin is frequently found in the urine of the newborn and even more consistently in the premature infant.

The finding of a relatively high hydrogen ion concentration, the limitations of the kidneys' capacity to regulate internal environment and the lowered plasma osmotic pressure suggest that young infants have a very slight chemical margin of safety. Consequently, any disturbance such

as diarrhea, infection or improper feeding can lead rapidly to severe acidosis and abnormal fluid balance manifested by dehydration at one extreme or edema at the other. Proper recognition of these factors is vitally important from a therapeutic point of view.

Although small amounts of urine are usually found in the bladder at birth, the newborn may not void for 12–24 hours or longer (Table 24).

TABLE 24.—Average Daily Secretion of Urine

Age	Cc./24 Hr.
1 and 2 days	15– 50
3–10 days	50–300
10 days to 2 mo.	250–400
2 mo. to 1 yr.	400–500
1–3 yr.	500–600
3–5 yr.	600–750
5–8 yr.	700–1000
8–14 yr.	700–1500

Excretion after this period is frequent. The specific gravity of the urine during the first few days is higher than during the remainder of infancy, when the average values for healthy subjects range from 1.002 to 1.008. By age 5 or 6 this value differs little from that for adults. Fluid intake and other factors obviously influence the results. The reaction of the initial urine of the newborn is quite acid but later approaches neutrality. Throughout the first year of life the urea content is relatively low. However, on the basis of body weight, the amount of urea excreted in 24 hours is greater in childhood than in adult life. As might be anticipated from the foregoing discussion, the concentration of phosphates, chlorides and sulfates is low early in life but gradually increases with age, especially as more solid food is added to the diet. The percentage of uric acid found in the urine in the neonatal period is much higher than it is subsequently.[3, 52] The cause of this is not known. The excretory rate of uric acid remains relatively high throughout early childhood. The relation of urinary uric acid to urea is 1:14 in the newborn and 1:70 in the adult. Creatine is excreted in variable but large amounts by the infant and to a lesser degree by children to the time of puberty, when it ceases in males and is markedly decreased in females. Creatinine output, conversely, increases throughout the growing period, the quantity being directly related to the amount of body musculature.[52] The quantity excreted by the newborn is about 1–3 mg. per kg. of body weight daily, 10–20 mg. at 2 years of age and 20–40 mg. at maturity.

THE GENITAL ORGANS‡

The relative weight of the testes is the same in the newborn and the adult. The periods of greatest growth are in infancy and again during adolescence, with relatively slow increase in weight between these periods. There is a fourfold increase in all three dimensions from birth to adult life. The seminiferous tubules at birth are solid but during childhood acquire lumens and increase in size. With puberty they enlarge more rapidly. The spermatogonia increase in size and number during childhood and at puberty begin to show the process of maturation. The interstitial cells of Leydig also increase in number from birth to puberty.[48]

The testes lie at the site of the future abdominal (internal inguinal) ring from the fourth to the seventh fetal month. During the latter month they become enclosed in the tunica vaginalis, pass through the inguinal canal and by the middle of the eighth month are usually attached to the fundus of the scrotum. In over 90 per cent of newborns the testes are found in their final position in the scrotum. The canal is obliterated in part or in toto in more than 80 per cent of infants over 2 months of age.[50]

The ovaries grow rapidly during early postnatal life and have doubled their weight by age 6 months. Between the ages of 12 and 15 years their weight is again doubled (see Table 33, p. 209). The cortex of the ovary, consisting mainly of primordial follicles, forms a thicker portion in the newborn than in later life. It has been estimated that there is a decrease of 90 per cent in the number of ova from birth to maturity. Undeveloped and atretic graafian follicles are common in childhood.

During the first weeks of life the uterus undergoes involution and its weight is decreased by one-half from that at birth. The hypertrophy originally present is due to hormone stimulus from the mother. The birth weight of the organ is not regained for about 10 or 11 years. Until adolescence the length of the cervix is twice that of the body of the uterus. Normal relationship is brought about by growth of the corpus uteri while the cervix remains relatively stationary.[50] In adults the lengths of the lumens of the cervix and uterus are about equal. The uterine and cervical glands are simple and tubular until adolescence, when they become longer and branched and undergo the changes characteristic of menstruation.

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‡Further discussion of these organs, particularly endocrine relationships, will be found in Chapter 9.

INCREMENTS OF GROWTH

The measurement of the body at regular intervals during its period of growth reveals certain trends in the rate of change common to all normal children. Fetal curves show a phase of slow growth in the early period, a rather marked change in rate about the middle of fetal life and a rapid growth thereafter to birth (Fig. 1, p. 31). Growth curves of children from birth to adult life have been presented in Chapter 4.

Certain organ systems also undergo fairly definite patterns of growth.

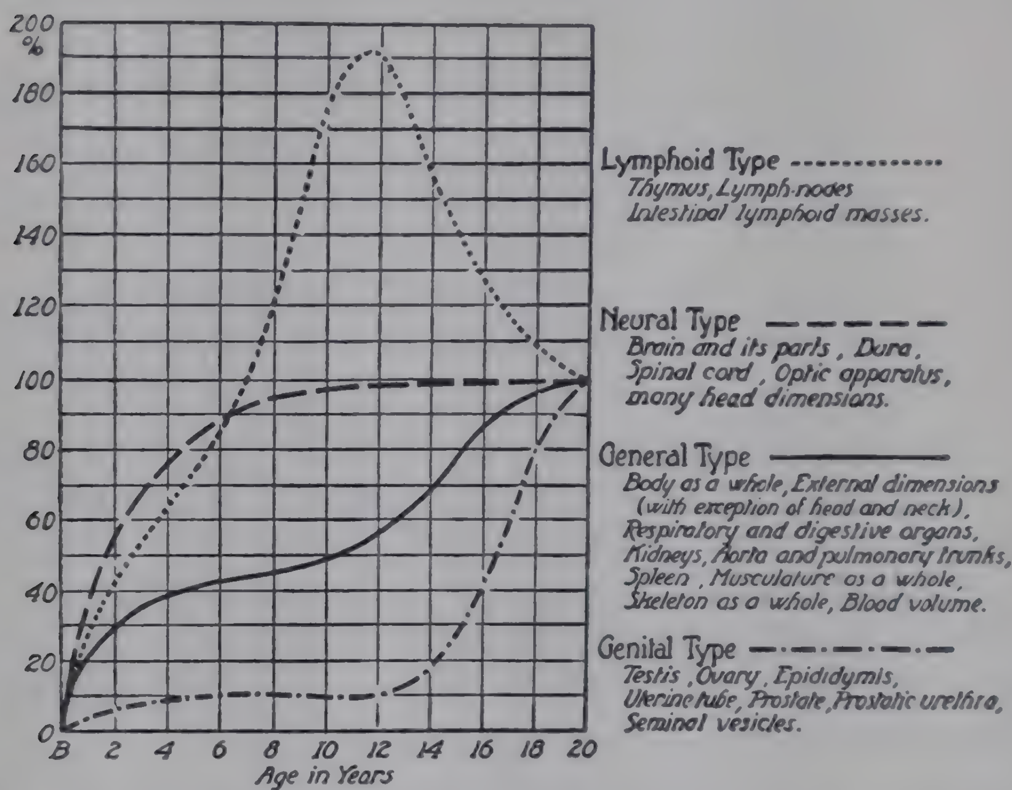

FIG. 23.—Organ growth curves, drawn to a common scale by computing their values at successive ages in terms of their total (average) postnatal increments. (From Harris, J. A., *et al.*: *The Measurement of Man* [Minneapolis: University of Minnesota Press, 1930].)

The organs of respiration, circulation, digestion and excretion follow the pattern set by the body as a whole, as exemplified by height or weight curves of a child. Rapid postnatal growth, which slows in later infancy and ceases before puberty, is characteristic of the central nervous system, the eye and much of the auditory apparatus; this is known as the *neural type* of growth. The *genital type* of growth, typical of the sex organs, shows little increase during early life but a rapid development just before and coincident with puberty. The *lymphoid type* of growth is character-

ized by rapid growth throughout infancy and childhood, ceasing at about the time of puberty and followed by involution. This last type is typical of the tonsils and adenoids, thymus, splenic follicles, lymph nodes and the

TABLE 25.—AVERAGE WEIGHTS OF ORGANS AT DIFFERENT AGES (GM.)

	NEWBORN	1 YR.	6 YR.	PUBERTY	ADULT
Brain	350	910	1,200	1,300	1,350
Heart	24	45	95	150	300
Thymus	12	20	24	30	0–15
Kidneys (both)	25	70	120	170	300
Liver	150	300	550	1,500	1,600
Lungs (both)	60	130	260	410	1,200
Pancreas	3	9	...	40	90
Spleen	10	30	55	95	155
Stomach	8	30	...	80	135

lymphatic tissue of the intestines. The four types of growth curves are illustrated in Figure 23.

Table 25 shows the weights of various organs at different ages. (Similar figures for the endocrine organs are given in Table 33, p. 209.)

SUMMARY OF ORGAN DEVELOPMENT

Musculature Throughout the span of growth there is an increase in muscle mass, with greatest increase during adolescence. Increase in skill, which involves musculature, is more intimately related to maturation of the nervous system.

Skeleton Bone growth passes through successive stages of development from connective tissue to cartilage to osseous tissue. The stages are important as measures of physical maturity, completion of calcification indicating the end of the growing period.

Nervous system Growth and maturation of the central nervous system are most rapid during infancy and early childhood, reflected in part by rapid growth of the head during this time. Increased permeability of the blood-brain barrier shortly after birth is reflected in the physical and chemical differences of the cerebrospinal fluid during early infancy and later life.

Special senses Most of the special senses are well developed at birth, although their association with higher centers comes about gradually during early life. Vision, owing to continued growth and development of the eyes, does not assume adult level until after the middle of childhood.

Reflexes The disappearance of some of the reflexes originally present

and the appearance of new ones are valuable indications of the integrity of the nervous system.

Circulatory system With birth there is considerable change in the paths and relative volumes of blood flow, reflected in the loss of certain fetal structures and changes in the heart and major vessels. Variations in pulse rate, blood pressure, heart sounds (including functional murmurs) and rhythm characterize development of the circulatory system. There is a steady increase in blood volume throughout the growing period, but this is not directly related to size.

Lymphatic system The entire lymphatic system is characterized by considerable growth throughout childhood, followed by involution as maturity is approached. Hyperplasia and hypertrophy may be pronounced during early life in response to infection.

Blood Not until midchildhood does the peripheral blood picture become the same as that of the adult. The differences are apparent in the numbers and types of cells as well as response to infection and noxious agents. Chemical components of the blood fluctuate during the neonatal period, but stabilization and homeostasis are slowly achieved during the first year of life and are relatively well maintained thereafter in health.

Digestive system Although there is considerable evidence that the digestive system is immature at birth, in usual circumstances there is no impairment of absorption or utilization of the main foods except fat. Liver function, based on adult standards, is definitely immature. Roentgenographic studies of the intestinal tract reveal some changes in position of parts with growth and some mechanical differences appear with advancing age.

Respiratory system Initiation of respiration and the associated changes are among the most important events occurring at birth. The newborn infant possesses some immunity to anoxia; nevertheless beyond a certain point, function of the central nervous system is jeopardized by anoxia. Breathing at first is irregular, in both rate and depth; this persists beyond the neonatal period. Until about the sixth year respiration is largely maintained by the diaphragm; subsequently the thorax plays an equally important role. Anatomic differences between child and adult are of considerable clinical importance relative to symptomatology and physical examination.

Urinary system The kidneys are physiologically immature at birth and for nearly a year thereafter. This accounts for the ease with which fluid and electrolyte imbalances may occur during infancy with illness. Both the premature and the newborn infant are in a state of well compensated acidosis due to borderline renal function.

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8

Osseous Development

Roentgenologic study of the bones may be of great aid to the pediatrician in evaluating physical development from birth through adulthood. Essentially the record of osseous development depends on two features: growth of the area undergoing ossification, and deposition of calcium in that area. The two do not necessarily keep pace with each other nor are they always present together. In this chapter will be discussed various methods which have been successfully used in the study of osseous development and their application to measurements of normal growth and development of the child.*

The appearance and union of the various centers of ossification follow a fairly definite pattern and time schedule from birth to maturity. This process provides, through x-ray studies, a valuable criterion for estimating normal and abnormal growth. The skeletal maturity of any individual is known as the *bone age*. It must be realized that in this field, as in others in which measurements of growth are made, there is no simple formula for deriving or evaluating growth trends.

In certain conditions, such as precocious puberty, there may be advance of the bone age over the chronological age.[8] Prematurity, hypothyroidism, malnutrition and chronic infection may cause a retardation of the bone age.[15] It is probable that, as the child grows older, he becomes increasingly less susceptible to the effect of those influences that disrupt the normal process of skeletal maturation. In early life there may be a delay in the appearance of the centers and there may also be a disorganization of the sequence of appearance. Interruption apparently is never present in the order of union although that union may be greatly delayed.[5, 12, 13, 16]

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*See also pages 129 ff. for discussion of skeletal development.

Ossification Center	Birth Weight, Gm.					
	Under 2,000	2,000–2,499	2,500–2,999	3,000–3,499	3,500–3,999	4,000 or More
Calcaneus						
White boys	100%					
girls	100					
Negro boys	100					
girls	100					
Astragalus						
White boys	72.7	100%				
girls	83.3	100				
Negro boys	90.9	100				
girls	100	100				
Dist. femoral epiphysis						
White boys	9.1	75.0	85.3%	100%	100%	
girls	50.0	91.7	98.0	100	100	
Negro boys	18.2	88.5	90.7	94.0	100	
girls	50.0	93.8	99.0	100	100	
Prox. femoral epiphysis						
White boys	0.0	18.8	52.9	78.8	84.1	97.1%
girls	0.0	54.2	75.5	85.7	90.7	90.5
Negro boys	0.0	38.5	62.7	76.0	80.0	92.9
girls	14.3	40.6	76.7	88.1	86.4	100
Cuboid						
White boys	0.0	6.2	14.7	39.8	44.3	60.0
girls	0.0	37.5	57.1	65.2	70.4	76.2
Negro boys	0.0	23.1	43.8	58.0	68.2	100
girls	21.4	37.5	68.0	78.2	81.8	75.0
Head of humerus						
White boys	0.0	7.7	13.8	41.9	49.0	59.1
girls	0.0	5.6	25.8	41.9	69.4	86.7
Negro boys	0.0	0.0	15.2	27.6	48.4	63.6
girls	0.0	10.7	22.7	52.6	38.9	100

*Modified from Christie.[3] Figures in each column are percentage of infants in whom the center was present. With some variations, incidence is higher in Negro than in white infants and in girls than in boys for a particular weight group.

The normal variation in bone maturation may be great and must be taken into consideration when the data are being evaluated. There are definite racial and sex variations (Table 26). The Negro, for example, shows more rapid maturation than does the Caucasian, and girls are usually ahead of boys by several months during early childhood. In the second decade there is an even greater difference between boys and girls. There are also marked individual variations, and in infancy the bone age

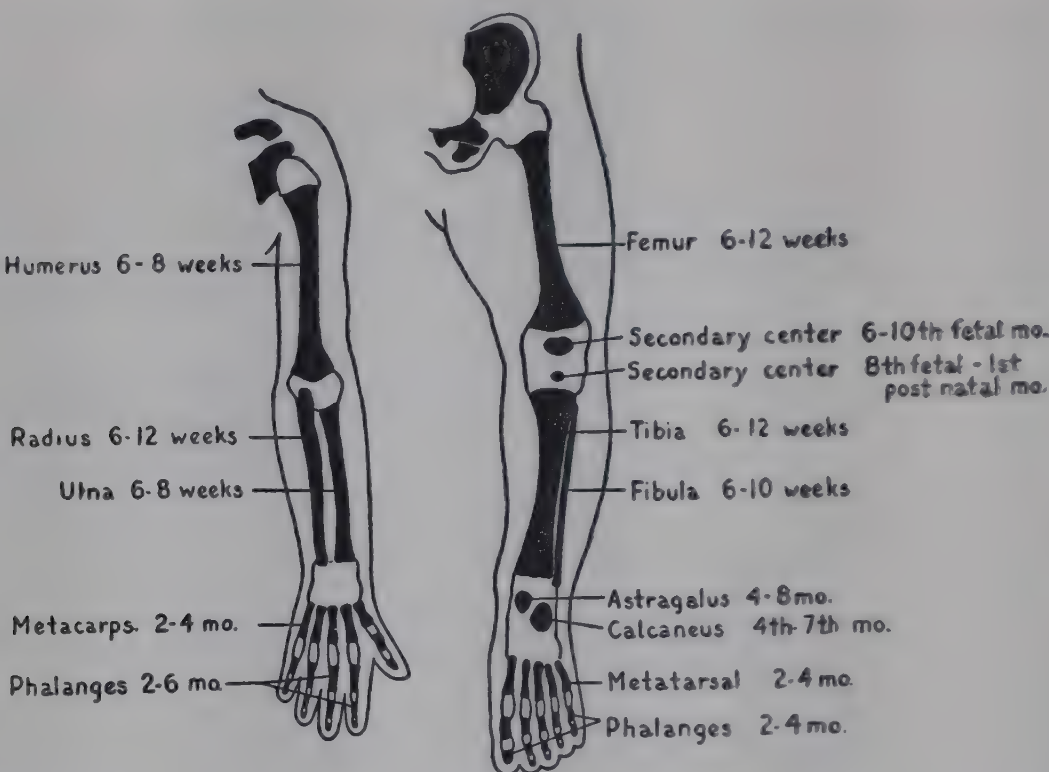

FIG. 24.—Fetal ossification centers, showing average time of appearance in fetal weeks or months. (From Caffey, J.: *Pediatric X-Ray Diagnosis* [2d ed.; Chicago: Year Book Publishers, Inc., 1950].)

may vary from the chronological age by one year in either direction without necessarily being abnormal. This so-called "normal variation" may be as much as two years at the end of the first decade. The sizes of centers, their contour and texture may also be considered in regarding bone age, and any abnormality should be noted, such as epiphyseal dysgenesis in hypothyroidism.[1-3, 5, 13]

Ideally, films of the entire skeleton should be studied before bone age is determined. For practical purposes, however, the bones of wrists and ankles, including the feet, are usually satisfactory. In very early childhood the small bones of the foot undergo more rapid changes and for this reason

are most satisfactory during the early months of life for use as a measure of development.

All of the primary ossification centers for the tubular bones appear during fetal life (Fig. 24). The secondary centers usually appear after birth, except the distal epiphysis of the femur, where ossification takes place during the last two fetal months. Therefore absence of this center is good presumptive evidence of prematurity. The center in the proximal epiphysis

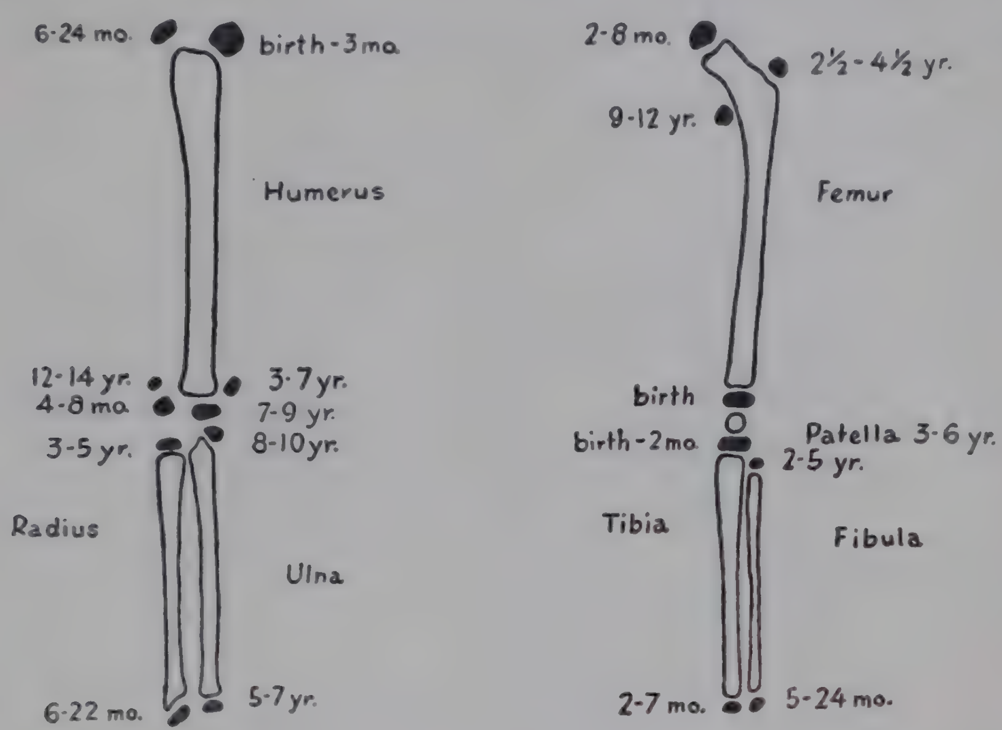

FIG. 25.—Secondary ossification centers, showing average time of appearance. (From several sources.)

of the tibia is present in approximately two thirds of full term infants at birth. The time schedule of appearance of secondary centers is shown in Figure 25.

Figures 26 and 27 show the normal maturation of the bones of the hands and feet in both sexes. Rarely, one or more carpals are present at birth. Table 27 shows the time of appearance of carpal bones in both sexes, and Figures 28–42 show graphically the sequence of appearance of the carpal centers.* The time of union of the epiphyses and diaphyses is given in Table 28.

The rate of linear growth of tubular bones may be of value when a

*For an excellent and detailed roentgen study of osseous development of the hand and wrist, see Greulich, N. W. and Pyle, S. I.: *Radiographic Atlas of Skeletal Development of the Hand and Wrist* (Stanford University, Calif.: Stanford University Press, 1950). This is a continuation of the Brush Foundation studies of human growth initiated by the late T. Wingate Todd.

TABLE 27.—PERCENTAGE OF CHILDREN IN WHOM SPECIFIED CARPAL BONES HAVE APPEARED*

Bone	Sex	Age, Yr.																
		B	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Capitate	F	8	96	100														
	M	2	98	100														
Hamate	F	8	96	100														
	M	2	98	100														
Triangularis	F	0	20	52	79	100												
	M	0	22	50	57	92	84	93	100									
Lunate	F		0	32	50	80	91	99	100									
	M		8	18	36	64	64	87	98	99	100							
Navicular	F				12	30	61	95	99									
	M				4	17	34	51	75	92	99	100						
Multangulum maj.	F			4	18	53	74	94	99									
	M				4	14	33	51	72	88	96	97	100					
Multangulum min.	F				15	40	65	95	100									
	M				4	22	29	48	81	95	100							
Pisiform	F								1	19	50	79	96	100				
	M									2	6	22	28	66	95	99	99	100

*From Nelson,[10] after Flory.

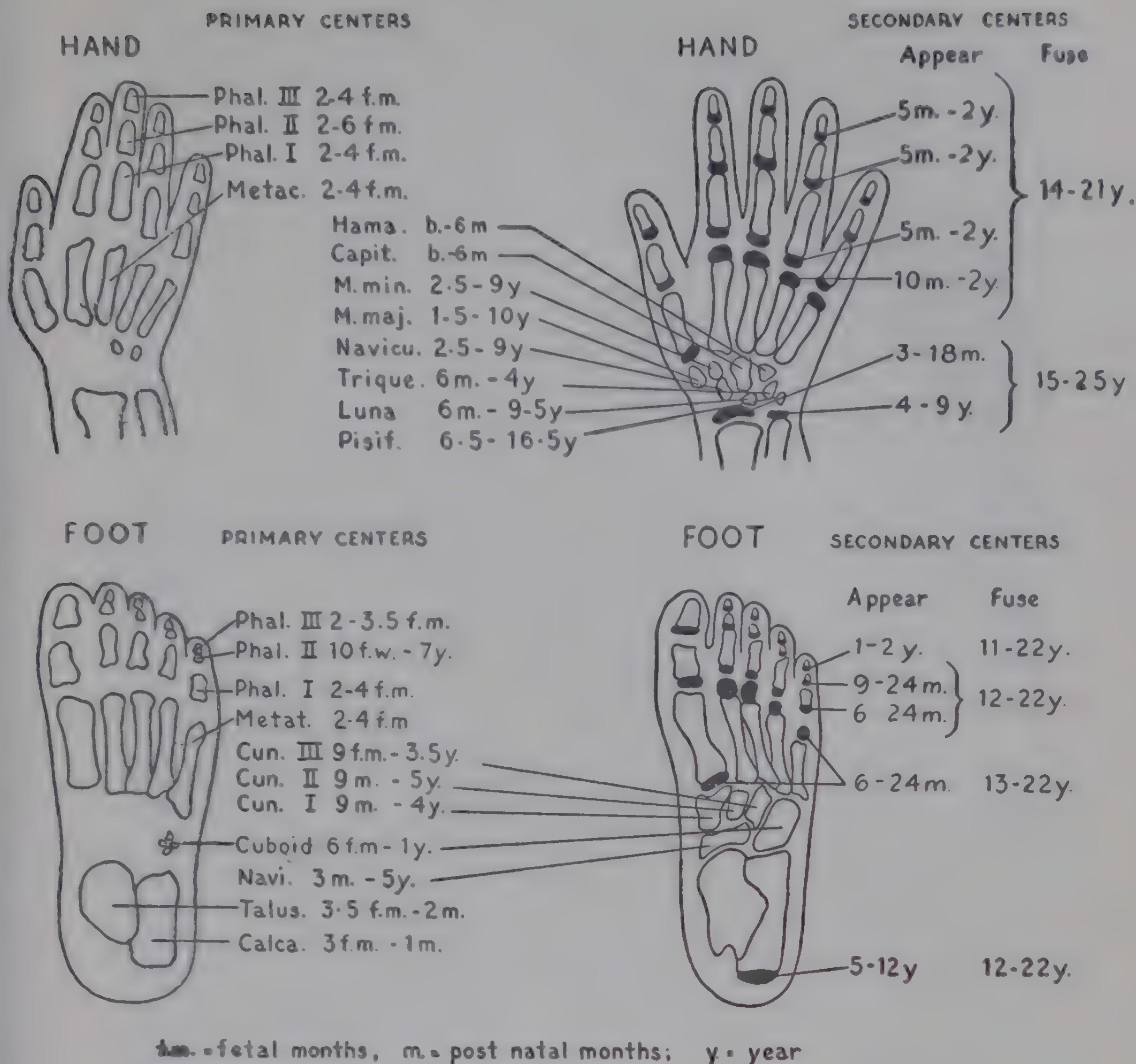

FIG. 26.—Ossification centers of the hands and feet, showing time of appearance. Note the wide range of "normal" and compare with Table 23. (From Caffey, J.: *Pediatric X-Ray Diagnosis* [2d ed.; Chicago: Year Book Publishers, Inc., 1950]; modified from Scammon in *Morris' Human Anatomy*.)

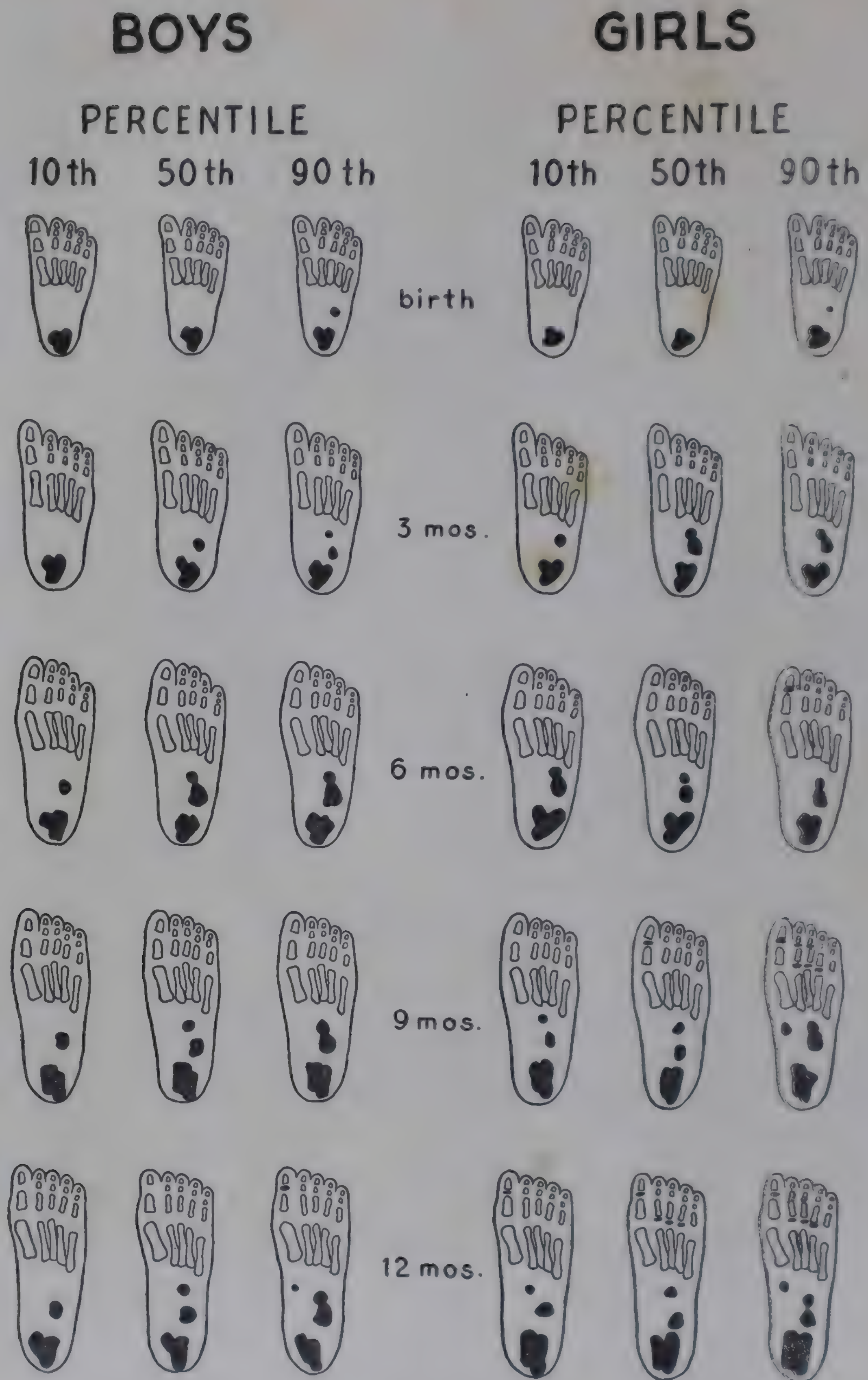

FIG. 27.—Normal maturation of the bones of the feet from birth to 1 year expressed as percentiles. (From Caffey, J.: *Pediatric X-Ray Diagnosis* [2d ed.; Chicago: Year Book Publishers, Inc., 1950]; according to Stuart.)

FIG. 28 *(above left)*.—Bone age in the newborn. (All subjects represented in Figures 28–42 were average, healthy children examined at the University Hospital over a period of years.)

FIG. 29 *(above right)*.—At 1 year, the capitate and hamate are present.

FIG. 30 *(below left)*.—At 1–2 years the distal epiphysis of the radius calcifies.

FIG. 31 *(below right)*.—Between 2 and 3 years the triangularis appears and the epiphyses of the metacarpals and phalanges are added.

FIG. 32 *(above left)*.—Between 3 and 4 years the lunate is added. (In boys it may not appear until later.)

FIG. 33 *(above right)*.—Between 4 and 5 years the major multangulum appears.

FIG. 34 *(below left)*.—Between 5 and 6 years (or slightly later in boys) all carpal centers except the pisiform become apparent.

FIG. 35 *(below right)*.—By age 7 the distal epiphysis of the ulna has appeared.

FIG. 36 *(above left).*—Between 7 and 8 years there is no change.

FIG. 37 *(above right).*—Between 8 and 9 years, except for growth, there is little change.

FIG. 38 *(below left).*—Between 9 and 10 years there are no changes, although in girls the pisiform may appear.

FIG. 39 *(below right).*—Between 10 and 13 years the pisiform appears. (It can be seen here beneath the triangularis.)

more rapid method of appraisal of bone development is needed than can be furnished by carpal or tarsal maturation. This may be especially important in evaluating therapy in cretins. Figure 45 shows a normal growth curve for the radius during infancy.[17] The average increase in length is about 0.25 cm. per month during the first year, then decelerates to about

TABLE 28.—Average Age of Union of the More Important Epiphyses*

Age, Yr. Boys	Age, Yr. Girls	Union of Epiphyses
6	6	Head and greater tuberosity of humerus
7	7	Ischium and pubis
12	12	Trochlea and capitellum of humerus
14	13–14	Olecranon and ulna
14	13–14	Epiphysis of calcaneus
15–17	14–16	Proximal epiphysis of radius
15–17	14–16	Trochanter and head of femur
16–18	15–17	Epiphyses of metacarpals and metatarsals
17	16	Coracoid
18–20	17–19	Distal epiphysis of radius
18–20	17–19	Distal epiphysis of ulna
18–20	17–19	Distal epiphyses of tibia and fibula
18–20	17–19	Acromion
18–20	17–19	Head and greater tuberosity to the humerus
18–20	17–19	Distal epiphysis of femur
18–20	17–19	Proximal epiphyses of tibia and fibula

* From several sources.

TABLE 29.—Average Length (Cm.) of Long Bones (Shaft) At Various Ages*

Age, Yr.	1	2	4	6	8	10	12
Humerus	10.6	13.0	16.5	19.3	22.0	24.5	27.0
Radius	7.9	9.7	12.3	14.4	16.3	18.1	19.9
Ulna	9.0	10.9	13.7	15.9	17.8	19.6	21.7
Femur	13.5	17.1	22.4	27.1	31.5	35.2	38.3
Tibia	10.9	14.0	18.4	22.1	25.8	29.2	32.6
Fibula	10.5	13.6	18.2	21.9	25.4	28.7	31.8

*From Maresh.[9]

0.12 cm. per month for the last six months of the second year of life. Table 29 gives the average length of various long bones at different ages.

In Table 30 we have attempted to summarize, as briefly as is practical, the best criteria for measurement of osseous development at different ages. Reference to it will suggest the anatomic area most likely, in roentgeno-

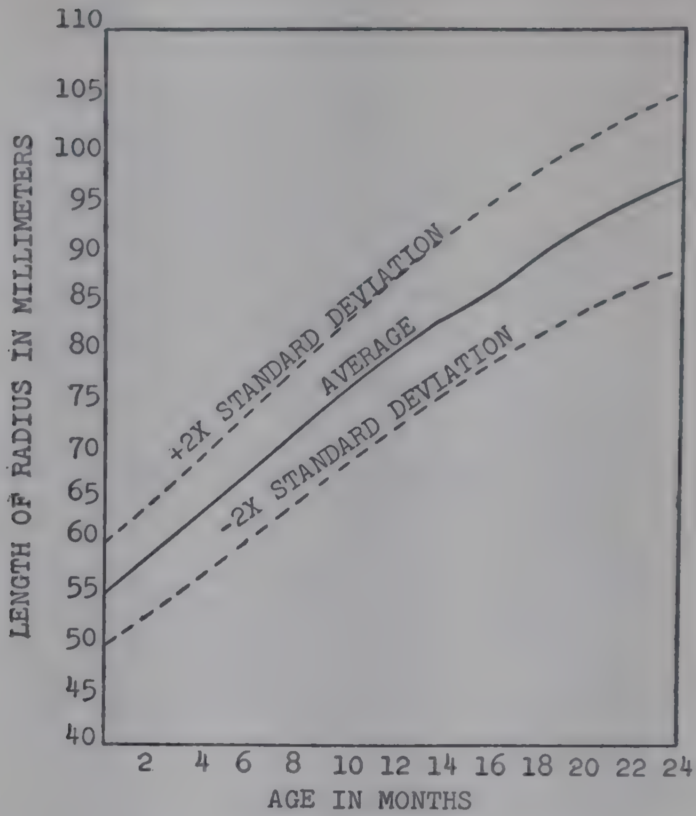

FIG. 45.—Rate of growth of the os radius during the first two years of life. (From Woolley, P. V., Jr., and McCammon, R. W.: J. Pediat. 27:229, 1945.)

TABLE 30.—WORKING TABLE FOR COMPARISON OF CHRONOLOGICAL AND BONE AGES*

AGE	MEASURE OF OSSEOUS DEVELOPMENT
Birth	Distal epiphysis of femur Astragalus, cuboid, calcaneus
1 yr.	Wrist—capitate, hamate, distal epiphysis of radius Ankle—addition of cuneiform III, distal epiphysis of tibia
2 yr.	Capitellum of humerus Wrist—no change Ankle—addition of epiphysis of fibula
3 yr.	Wrist—addition of triangularis Ankle—addition of cuneiform I
4 yr.	Wrist—addition of lunate Ankle—addition of cuneiform II, navicular Hip—epiphysis of greater trochanter
5 yr.	Wrist—addition of major multangulum, navicular Knee—patella

* From several sources.

TABLE 30.—Working Table for Comparison of Chronological and Bone Ages *(cont.)*

6 yr.	Wrist—addition of minor multangulum, epiphysis of ulna Shoulder—union of head and tuberosity of humerus
8 yr.	Ankle—epiphysis of calcaneus Union of ischium and pubis
10 yr.	Wrist—pisiform
12 yr.	External condyle of humerus Union of trochlea and capitellum of humerus
14 yr.	Union of proximal epiphysis of radius Union of olecranon and ulna
16 yr.	Union of epiphyses of metacarpals and metatarsals Appearance of crest of ilium
18 yr.	Union of distal epiphysis of radius and of ulna Union of distal epiphysis of tibia and of fibula

grams, to give information pertaining to bone age. It must be stressed that such a table has definite limitations. The stages of osseous development given are averages only. Studies of large groups of children have revealed that among normal subjects 50 per cent will follow the usual pattern, 25 per cent will be advanced and 25 per cent will be retarded when checked against a set scale of skeletal development.[16] It was also found that, in general, the stage of osseous maturation correlated well with weight and height and sexual development. That is, the child whose height and weight were less than average for age also had repressed bone maturation and, correspondingly, in subjects above average height and weight bone development was advanced. A greater variation in this respect was found in girls than in boys.[14] Comparison with records of menarche revealed that by far the majority of girls menstruated first when their roentgenographic record of skeletal age was between 13.5 and 14 years. This observation correlated more distinctly than did chronological age.

Any list of conditions with which disturbances of osseous development occur (Table 31) should be qualified. Many exceptions will be noted in clinical practice. Apparently there are individual variations in the reaction to disease so far as skeletal structures are concerned. In general, endocrine disturbances cause more profound changes than infection, even when the latter is fairly severe and of long standing. Undernutrition causes retardation only when severe and of long duration.[5, 12, 16] Milder forms of disease which may influence height and weight usually do not interfere with

maturation of bone. Some chronic infections, notably pulmonary tuberculosis, may actually accelerate development.[16] The so-called "lines of arrested growth," transverse lines along the shaft of the diaphysis, are rather frequently related to past illness, but they may also occur in the absence of any such history. Brief illness, such as one of the exanthemas, bronchitis and diarrhea, may or may not cause a disturbance in the timetable of appearance of ossification centers or in the sequence of their appearance. Such a disturbance is more apt to be present in the first few years of life than at a later period. In general, those conditions which cause a retardation in the time of appearance of the centers of ossification will also cause a retardation in the rate of linear growth of bone. A notable exception to this is the genetic factor. We have seen children with normal height, weight and mental development and no history of disease who displayed

TABLE 31.—Pathologic Conditions Associated with Abnormalities of Osseous Development

Conditions associated with *advanced* osseous development
- Hyperthyroidism (acceleration is not a constant finding)
- Adrenogenital syndrome (tumor of the adrenal cortex or pituitary basophilism)
- Pubertas praecox (Fluhmann)
- Tumors of the ovary (granulosa cell, thecoma, teratoma)
- Interstitial cell tumor of the testes
- Pineal gland tumor (male only)
- Tumors of the third ventricle involving the hypothalamus
- Simple obesity associated with statural overgrowth
- McCune-Albright syndrome (polyostotic fibrous dysplasia)

Conditions associated with *delayed* osseous development
- Hypothyroidism
- Addison's disease
- Hypopituitarism (dwarfism)
- Pituitary cachexia (Simmonds' disease)
- Prolonged malnutrition
- Chronic illness
- Fröhlich's syndrome (adiposogenital dystrophy)
- Chondrodystrophy (achondroplasia)
- Hurler's syndrome (lipochondrodystrophy)
- Some cases of mental deficiency and mongolism

a "carpal age" three years below the chronological age as measured by Todd's *Atlas*.[13] Two of these were siblings and both followed almost identical patterns for skeletal growth (Fig. 42).

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9

Role of the Endocrine Glands in Normal Growth and Development

THE ENDOCRINE GLANDS play a vital role in growth by a specific effect of their hormones on growing tissue and by their influence on the body's metabolism. The pituitary (hypophysis), thyroid, parathyroids, adrenals, pancreas and gonads have fairly well defined functions (Fig. 46). The functions, if any, of the thymus and pineal body are not known.

THE PITUITARY GLAND

The anterior and posterior lobes of the pituitary are formed from separate ectodermal primordia. The anterior portion comes from the stomodeal depression known as Rathke's pouch which appears about the fourth fetal week. The time at which this tissue becomes physiologically active is not known, but by the twelfth fetal week its glandular character is apparent on histologic examination.[19]

When the anterior lobe is removed from a young animal, even though the animal is kept in excellent nutritive condition, growth ceases. Evans[8] has produced giantism in animals by the injection of pituitary extracts. A protein compound has been isolated from the anterior lobe that has a specific molecular weight and isoelectric point and caused resumption of growth in hypophysectomized animals. This compound produced an increased proliferation of epiphyseal cartilage cells in animals. These experimental facts plus clinical observations would seem to establish the existence of a growth-promoting hormone secreted by the anterior lobe of the pituitary.[8]

The pituitary also exerts a profound influence on energy metabolism.[4, 10] Oxygen consumption is greatly reduced in the hypophysectom-

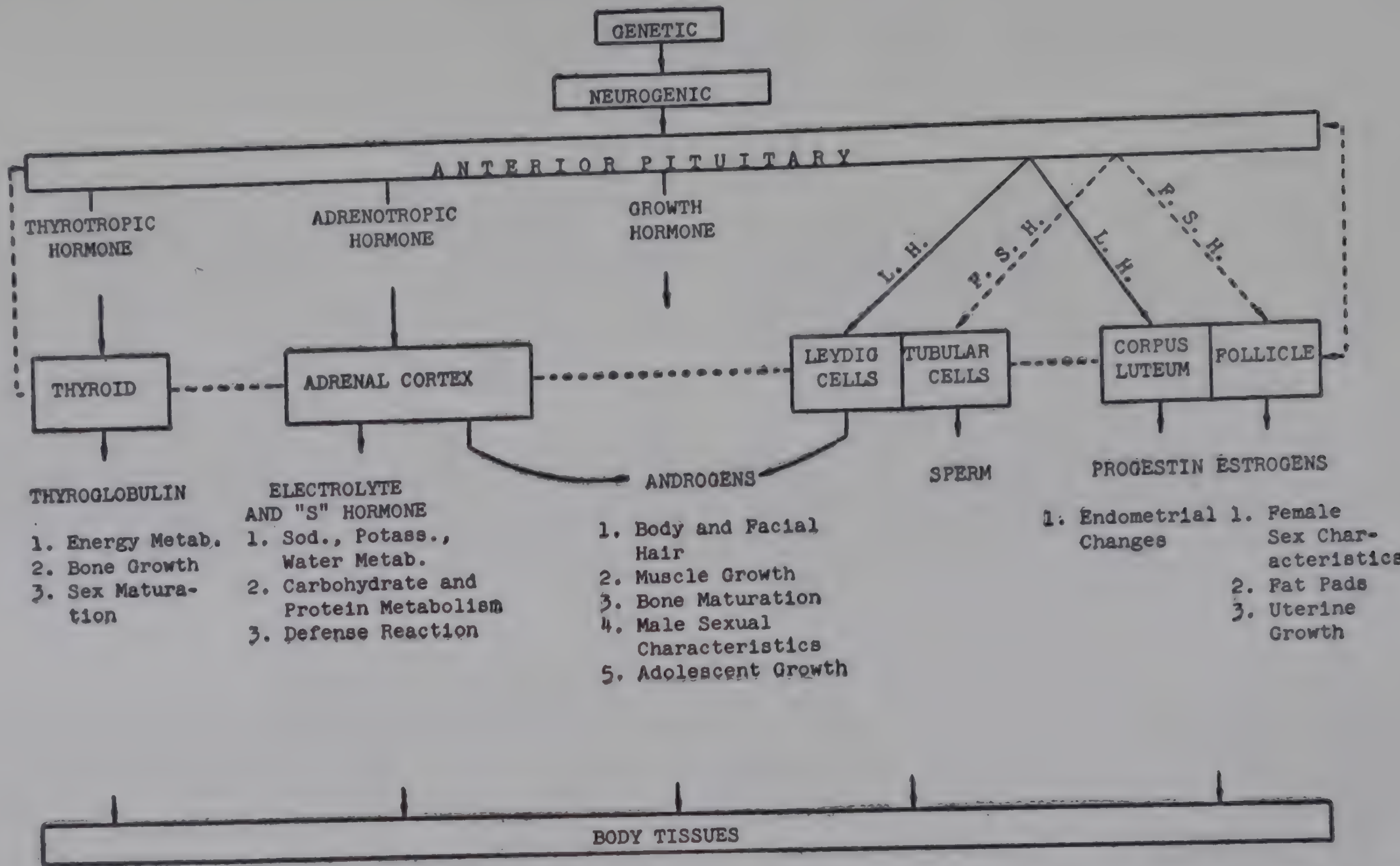

FIG. 46.—Functions of the endocrine glands related to growth and maturation and some of the factors believed to regulate their action. Length and size of the arrows are unrelated to the intensity or importance of action of the various hormones. *L.H.*, luteinizing hormone; *F.S.H.*, follicle-stimulating hormone. Broken arrows show the reciprocal action of the substances on one another.

ized animal. The patient suffering from pituitary cachexia always has lowered metabolic activity. Conversely, the acromegalic individual has an elevated basal metabolic rate. In thyroidectomized animals the injection of an extract from the anterior lobe causes an increase in oxygen consumption. This proves that the thyrotrophic hormone is not the cause of these changes.

Normal carbohydrate metabolism depends on a normally functioning pituitary gland. Continuous administration of certain extracts from the anterior lobe causes hyperglycemia, glycosuria and ketonuria in animals. This diabetogenic effect is believed to be mediated through the adrenal cortex and to result from blood-sugar–raising effects of the adrenal cortical hormone stimulated by the adrenocorticotrophic hormone (ACTH) of the pituitary. This type of diabetes is very refractory to insulin once it has become established. Examination of these animals has revealed that there is destruction of the islets of Langerhans.[7] Although it is now apparent that this diabetogenic hormone and the growth hormone are separate substances, it is interesting to note that several authors have observed that the diabetic child is taller than the norm for his age at the time of onset of diabetes mellitus.[31]

The metabolism of endogenous protein is reduced in hypophysectomized animals as evidenced by creatinine output in the urine and a negative nitrogen balance. Anterior pituitary substances will correct such a deficit.[4, 7] It is not known whether the substances that promote nitrogen retention and the growth factor are the same, but it is probable that they are. Finally, we know that by its stimulating target hormones affecting the thyroid, adrenals and the gonads, the pituitary exerts a strong though indirect influence on growth. These interrelations with other glands will be considered in discussions of the other endocrine organs.

Pathologic abnormalities of growth which are associated with pituitary disturbances are well known. Overactivity of the anterior lobe is the cause of giantism if it begins before puberty, and causes acromegaly if it occurs after puberty. In either case there is no acceleration of bone maturation. Hypoplasia or destruction of the anterior lobe leads to dwarfism in the prepubescent period. Such patients always show considerable retardation of skeletal development.[31] Although it is possible to have a defective secretion of the growth hormone alone, most of these individuals display some evidence of hypogonadism, hypothyroidism and hypoadrenalism as well. That is, these patients are usually panhypopituitary. It is therefore likely

that a combination of factors is responsible for the retardation of bone age.

Summarizing the evidence, one can state that the anterior lobe of the pituitary secretes a specific growth hormone whose principal actions are acceleration of bone growth and tissue building. Less directly the gland influences growth by the action of its hormones on other glands of internal secretion. The role of the pituitary in metabolism (energy, carbohydrate and nitrogen) must also be considered a modifying factor in the final growth pattern.

THE THYROID GLAND

The thyroid gland is probably second only to the pituitary in relative importance in its influence on growth and development.

The thyroid makes its appearance toward the end of the fourth fetal week as a bilobed diverticulum from the floor of the pharynx. Toward the end of the fourth month colloid can be found in the center of the cell mass and there is evidence that shortly after this time the gland becomes physiologically active. Accessory thyroid tissue may be found along the course of the thyroglossal duct from the base of the tongue to the root of the neck. Occasionally thyroid glands are found substernally.[19]

Sections of the thyroid taken at birth or a few days thereafter show a decreased amount of colloid material, nearly all the vesicles being empty. There follows a gradual reaccumulation of the material in the gland. These observations suggest that during gestation there is active function of the thyroid gland and following birth a period during which the current secretion is insufficient for the body's needs.[25] In addition, the basal metabolism has been shown to be low at birth and to increase gradually during the first month of extrauterine life, then to increase more rapidly for the first year of life. The fetal thyroid contains iodine as early as the latter part of the third fetal month and thyroxine has also been demonstrated at this time. By the end of fetal life the percentage of iodine as thyroxine iodine is not different from the same figures for adults.[25]

It is believed that the placenta is able to transmit thyroid hormone either from the mother to the fetus or from the fetus to the mother. This is the explanation offered for the delay in development of symptoms in sporadic cretins born of a normal mother; i.e., the cretin maintains normal metabolism while the mother supplies the necessary hormones. However, measurements made at birth of maternal blood and of cord blood have shown a much lower value for thyroid hormone iodine in cord blood, in

some less than half the amount present in the blood of the mother.[25] Also it is well known that the mental development of cretins who receive early and adequate therapy is often below par. This would suggest that the maternal thyroid alone does not furnish sufficient hormone for both organisms or that some barrier exists to free passage of the hormone through the placenta.

The thyroid hormone is believed to act as a catalyst to increase the oxidative processes of the tissues or to increase the activity of the respiratory enzymes. Tissue slices from a hyperthyroid animal have increased metabolism; those from a hypothyroid animal have decreased metabolism. The action of a single administration of desiccated thyroid or thyroxin to a hypothyroid animal or man has a relatively slow onset and a prolonged effect on the basal metabolism; its maximal effect is reached in eight to 10 days and usually lasts for several weeks.[10]

Most of our knowledge of the action of thyroid hormone on man has been obtained from the study of patients with abnormal function of the thyroid. One can safely say that the gland "has a profound effect on the growth and development of the body, and it has a stimulating effect upon total metabolism."[4] Briefly outlined, a normally functioning thyroid (1) promotes body growth and development, (2) promotes skeletal growth and development, (3) promotes sexual maturation, (4) maintains normal mental development, (5) increases the metabolic rate, and (6) maintains normal cutaneous texture, including growth and luster of hair. These undoubtedly are not separate functions but part of a total pattern regulated by the thyroid hormone.

The absence of thyroid secretion or deficiency of it results in the clinical picture of cretinism or congenital myxedema. There are stunting of growth, mental retardation and slowing of bone growth and maturation. The specific action of thyroid therapy in correcting growth in these patients is well known. In the normal animal large doses of thyroid will not accelerate growth, nor does it have any effect on growth of the pituitary dwarf. This hormone must act as a catalyst for the action of the pituitary hormone and does not otherwise influence growth.[9, 31]

The relation of the thyroid to other endocrine glands has been clearly shown. Its secretion is apparently necessary for normal maturation and functioning of the gonads. Conversely, in animals, castration usually leads to a reduction in size of the thyroid and decrease in metabolic rate.

A relationship between the thyroid and adrenals is indicated by the

following observations: (1) subjects with hyperthyroidism show increased susceptibility to epinephrine, (2) administration of thyroxin causes hyperglycemia only if the adrenal glands are intact, (3) injury to the adrenal cortex causes an increase in metabolic rate only if the thyroid is present in the animal, and (4) excretion of 17-ketosteroids is reduced with myxedema.[4, 17]

Hypophysectomy causes atrophy of the thyroid, and an acid extract of the anterior lobe of the pituitary has been prepared which stimulates the thyroid, causing many of the symptoms and signs of hyperthyroidism. Following injection of this extract the thyroid becomes hyperplastic and there are loss of its iodine content and an increase in the blood iodine content. This thyrotrophic hormone of the pituitary induces creatinuria, increases the calcium excretion and reduces liver glycogen in animals only

TABLE 32.—METHODS FOR DETERMINING THYROID FUNCTION AND RESULTS IN THYROID DYSFUNCTION

HYPOTHYROID	METHOD*	HYPERTHYROID
Lowered	Basal metabolic rate	Elevated
Delayed	Osseous development; bone age	Accelerated (?)
Normal or high	Blood cholesterol	Normal or low
Decreased	Urinary creatine	Normal or increased
Normal or decreased	Serum phosphatase	Normal
Increased	Blood carotene	Normal

*See text for discussion of methods.

when the thyroid is present. Conversely, the thyroid exerts an influence over the pituitary, for thyroidectomy in animals causes hypertrophy of the anterior portion, degeneration of basophilic cells and reduction in the number of acidophilic cells.[4, 10]

There are several means of determining normal and abnormal thyroid function (Table 32). The more important of them follow.[35]

1. *Basal metabolic rate* (see p. 219).—In hypothyroidism the B.M.R. may be 45 per cent below normal. In hyperthyroidism it may be elevated as much as 100 per cent. Metabolic studies are somewhat difficult to carry out, particularly in younger children, and the results must be interpreted with care.

2. *Osseous development* (see Chapter 8).—This is one of the more reliable and practical methods for estimating thyroid function in children. Any marked retardation in bone maturation should make one suspect hypothyroidism, although there are other causes of retarded bone develop-

ment (p. 190). Epiphyseal dysgenesis is found frequently in cretinism and juvenile myxedema. Retardation may be present at birth in the cretin or a latent period of weeks or months may pass before such changes are apparent roentgenologically.[35]

3. *Serum cholesterol.*—Although there are wide variations of "normal" cholesterol levels at different ages, a striking elevation of the blood content may indicate deficient thyroid function. Other diseases in which the cholesterol level may be elevated include nephrosis, chronic nephritis, lipemia, some of the lipoidoses (Niemann-Pick disease) and von Gierke's disease. Of greater value than an isolated determination is a study of the response of the blood cholesterol content to the administration and withdrawal of thyroid therapy. After a brief course of desiccated thyroid therapy is discontinued, the cholesterol values rise sharply in a child with hypothyroidism and only slightly in a normal child. The second determination should be made three to four weeks after withdrawal of the medication.[35]

4. *Urinary creatine.*—Decrease in excretion of urinary creatine in hypothyroidism has been demonstrated. This probably reflects lowered muscle metabolism.

5. *Serum phosphatase.*—A decrease in the serum phosphatase content is found in hypothyroidism. This may be a reflection of the delayed osseous development. Normal values range between 5 and 14 Bodansky units according to a series studied by Talbot *et al.*,[30] whereas in all of their cretinoid patients the values were below 4.5 units. We have found this test helpful but not infallible.

6. *Blood carotene.*—The conversion of carotene to vitamin A depends on normal function of the thyroid gland. In hypothyroidism this conversion is defective and the blood level of carotene may be elevated. Normal values range from 5 to 40 calorimetric units. Vitamin A tolerance tests also show poor absorption in hypothyroidism and a resultant low blood level.[4]

7. Two methods still in a stage of being perfected are determination of serum protein-bound iodine and thyroid uptake of radioactive iodine. The former test has shown that the iodine level is below normal in the hypothyroid state, being less than 4.5 gammas. The degree and rate of pick-up by the thyroid gland of tracer-free radioactive iodine are conspicuously decreased in hypothyroidism as compared with normal subjects after the material has been ingested orally. Both methods appear to be more accurate, when properly carried out, than other available diagnostic tests.

Talbot and his co-workers[31] found in a group of clinically proved hypothyroid children that the various tests gave confirmatory results in the following percentages:

Serum phosphatase	90%
Osseous development	75%
B.M.R.	67%
Cholesterol levels	22%

THE ADRENAL GLANDS

The adrenal medulla originates from cells of the neural crest which also form the sympathetic ganglions. Very early in embryonic life these cells may be differentiated from the ganglion cells by staining with chromic acid, which they retain; this has led to the term "chromaffin cells." Similar clusters of chromaffin cells found along the aorta persist for many years following birth. The cells of the adrenal cortex arise from the splanchnic mesoderm. Early in fetal life two distinct layers of the cortex can be made out. The inner portion of the cortex, called the reticular zone, becomes mature and well differentiated by the third fetal month and vacuoles are formed in these cells. The outer portion remains a thin layer and is undifferentiated until after birth. In the neonatal period the adrenal gland has approximately 20 times the relative size found in the adult; this is due to persistence of the fetal reticular layer. By the end of the first year of life the number of these cells has decreased greatly; the final adult character of the adrenal cortex is not attained until about the third year. The adult reticular cells are derived by a process of differentiation from the fetal cells.[15, 19]

The adrenal cortex produces at least three groups of steroid hormones, according to their physiologic effect. Albright designated them water-electrolyte hormones, S(sugar)-hormones and N(nitrogen)-hormones.[1]

The first group, water electrolyte hormones, have the same or similar action as 11-desoxycorticosterone and influence chiefly water, sodium and potassium balance. They control sodium and potassium excretion by the kidneys through the mechanism of reabsorption. With a deficiency of these hormones there is an excessive loss of sodium from the body and an increase in serum potassium content. Secondarily the serum chloride level is lowered due to excessive chloride excretion. The extracellular fluid volume is depleted as a consequence of the electrolyte loss when water is carried off. Dehydration, weakness, microcardia and circulatory collapse are the end results. Conversely, an excess of desoxycorticosterone increases

the reabsorption of sodium in the kidney leading to elevation of the serum sodium level. Serum potassium content falls owing to excessive excretion, and intracellular potassium also is depleted. With the sodium retention there is an increase in the extracellular fluid volume, with resulting edema. Sodium tends to replace the intracellular potassium in order to maintain osmotic balance. If this exchange reaches any degree of magnitude degenerative changes appear and weakness, paralysis and cardiac failure occur. To bring about further extracellular-intracellular ionic balance the extracellular chloride concentration is decreased. This in turn is compensated for by a rise in serum bicarbonate content. The final result is slight hypernatremia, hypokaliemia, hypochloremia and increased serum bicarbonate content. Eventually hypertension may be present. In a normal individual the hormone output is such that these factors are kept in balance and are related to the sodium and potassium intake.[22]

The second group, or S-hormones, control carbohydrate-protein balances in the body. They differ chemically from the first group in having an oxygen atom attached to the eleventh carbon atom in the steroid nucleus. These hormones promote catabolism and gluconeogenesis from protein. When in excess they inhibit carbohydrate utilization by the body tissues and tend to cause increased fat deposition. This inhibiting action also produces a relative hyperglycemia which is resistant to insulin. Measurements of the excretory products of these oxysteroids have shown them to be present in infancy and that the rate of urinary excretion after age 5 is the same for children and adults.[22, 32]

Children with Addison's disease have a deficiency of both groups of hormones. This condition accounts for the lowered serum sodium content and hypoglycemia which are noted in these patients in crisis. There is also retardation of growth. Since the administration of sodium chloride and glucose will again promote growth in these subjects, Talbot has concluded that these adrenal cortex hormones are not essential to growth.[31]

The N-hormones, or androgens, constitute the third and final group. Experimental and clinical evidence indicates that these substances originate in the reticular layer of the cortex. In their physiologic action they resemble androgens from the testes since they promote both masculinization and nitrogen retention. In the female all androgens are derived from the adrenal cortex, whereas in the male a small but relatively potent portion comes from the testes as adolescence progresses.[31] The urinary excretory rate of these hormones is found by measurement of the 17-ketosteroids.

During the first eight years of life their output is negligible, but from that time until full maturity there is a rapid increase (Fig. 49, p. 207).

It appears that the last two and perhaps all three groups of hormones from the adrenal cortex are under the influence of at least two different pituitary adrenotrophic hormones. Under conditions of stress such as infections, severe burns and increased muscular activity the pituitary gland is activated and the adrenal cortex stimulated. An excess of S-hormones results. This is apparently a protective mechanism or defense reaction to damage. In addition to causing the physiologic changes already enumerated, in animals it will also increase most of the circulating immune bodies and in man will cause involution of the thymus, lymphocytic lysis and eosinophilic lysis.[15, 22] It is possible that an excess secretion of this group of hormones during illness in children accounts for the temporarily arrested growth due to nitrogen catabolism and inhibition of glucose metabolism by the body's tissues.[31]

Cushing's syndrome in children is characterized by obesity, plethora, atrophic striae of the skin, acne, hirsutism, muscular weakness, hypertension, osteoporosis ("fish vertebrae") and insulin resistance. As a rule the urinary output of oxysteroid-like substances is increased and the 17-ketosteroids are normal or slightly elevated. The growth of such children is impaired and they are frequently in a state of negative nitrogen balance, as would be anticipated from an excess of S-hormones. Since protein forms the network upon which calcium salts are deposited there are changes in the skeleton and vertebrae may collapse, resulting in actual reduction of stature.[1, 31]

In the adrenogenital syndrome the rate of growth is accelerated, including maturation of the skeleton, increased masculinization, acne, hirsutism and an increase in muscular development. Associated with such changes is a marked increase in the excretion of 17-ketosteroids. Occasionally this condition occurs in combination with Cushing's syndrome.[1, 31]

Although all studies do not agree, the majority favor the view that all three hormones of the adrenal cortex are present at the time of birth and that in most circumstances, with sufficient stress, the newborn cortex is capable of reacting in a similar fashion and to nearly the same degree for size as the adult cortex. On the basis of size, the newborn and infant excrete less of the 17-ketosteroids, but with proper stimulus the output is increased as in the older child. The normal excretion of oxysteroids by infants and small children, based on size, is similar in quantity and quality

to that by an adult. It likewise increases under stimulus. The effect of the electrolyte hormone on the kidney of the premature and the newborn infant may at times be paradoxical, but apparently only briefly and may simply reflect kidney immaturity and not some peculiar property of the cortical hormone. There is suggestive evidence that during the first few days of life a stronger stimulus of corticotropin is needed to obtain results qualitatively similar to those in the older child or adult, but within a few days there is a nearly equal response.[36–38]

From this brief survey of the available knowledge the following concepts may be postulated. (1) The adrenal glands are essential to life but growth may proceed in their absence if hydration and electrolyte balance are maintained. (2) In times of stress the cortical hormones may be of extreme importance. (3) Any direct influence on growth must depend on the relative amount secreted of the antagonistic S- and N-hormones. (4) The N-hormones have marked influence on skeletal maturation; however, it is not known just how great their role is normally.

GONADAL INFLUENCES ON GROWTH AND DEVELOPMENT

Considering the multiple alterations in sex hormone production during pregnancy in the mother and the exposure of the fetus to these alterations, it is not surprising that the most evident endocrinologic changes in the newborn are in the sex organs. In the female newborn the external genitalia are enlarged, including the clitoris. There is a thin, milky exudate from the mucous membranes of the labia for a week or two after birth. There may be a small amount of bloody discharge from the endometrium. These gross changes seldom last more than a week after birth, except for the swelling of the genitalia which may be perceptible for a month. Accompanying these gross changes are microscopic alterations of brief duration. The hyperplasia of the vaginal epithelium present at birth is rapidly followed by desquamation and establishment of the normal condition of infancy. The glycogen content of the epithelium is high at birth but soon falls and does not rise again until puberty. All of these neonatal phenomena can be produced experimentally by the administration of estrogens to newborn animals, and it has been shown that both male and female newborn children have relatively high blood levels of estrogens.[20, 25]

In the male, there may be prostatic hypertrophy during the neonatal period. This change is most marked in the anatomic homologues of the vaginal structures, i.e., the utricle and the prostatic urethra. Desquamation

and establishment of normal infant size rapidly follow birth. Occasionally there is acinar hypertrophy in the prostate of the newborn.[25]

Both sexes show enlargement of the mammary glands and secretion from them in about 80 per cent of all newborns and in a small proportion of premature infants. These changes are believed to be due to estrogens from the mother and prolactin (lactogen) from either the mother or the fetus or both. Prolactin is found in the urine of these infants before and during newborn lactation.[25]

The normally functioning gonad is necessary for proper development of the child. The effects of prepubertal castration demonstrate this: the muscles are less well developed, there is a greater deposition of fat in them and the bones are longer owing to failure of the epiphyses to close.[19] The time of closure of the epiphyses is closely correlated with the advent of puberty, and the average child grows about 2 in. after its onset. With this fact in mind, it is interesting to note that the castrate stops growing at the time puberty normally would have occurred. The same picture results whether the ovaries or the testes are removed. Overactivity of the testicular tissue in prepubertal boys results in early development of the secondary sex characteristics and perhaps even in the production of sperm.[33] This picture is found with interstitial cell tumor of the testes, and in all reported cases the patients stopped growing when much shorter than the mean for their age. Somewhat similar syndromes result from granulosa cell tumors in the ovaries in girls.[20]

The androgens secreted by the interstitial cells of the testes are activated by the gonadotrophins from the pituitary. Their physiologic properties are not essentially different from those previously described for the adrenal cortex. In boys the testes certainly are the most important source of androgens. Testosterone has been used effectively in some cases of dwarfism, in which it has led to increased muscular development, increased stature, accelerated bone maturation and eventually development of secondary sex characteristics.

Like testosterone, the ovarian estrogens normally are not secreted in effective amounts until shortly before puberty. Estrogens do not appear to have any growth-promoting properties except possibly by altering pituitary secretion. Estrogens do tend to accelerate bone maturation and stimulate production of the secondary sex characteristics.[30]

Further discussion of the role of the sex glands in growth and development will be found in the section on puberty (p. 205).

THE PARATHYROID GLANDS

The importance of the parathyroid glands to normal growth and development can be appreciated when it is realized that these glands are responsible for normal bone development which, in turn, is the limiting factor for statural growth. The parathyroid glands to a great degree regulate calcium and phosphorus metabolism in the body. However, their exact mode of action is not known. The following discussion is based on the theory of Albright,[2] who has done more work in this field than any other investigator.

Bone consists of an organic matrix in which is deposited a calcium-phosphate-carbonate complex called dahlite. All bone has both resorbing surfaces, under the influence of osteoclast cells, and bone-forming surfaces, under the influence of osteoblast cells. The osteoblasts are believed to elaborate the enzyme phosphatase. The fluid in contact with bone is normally maintained, in relation to the concentration of its constituents, by the kidneys. Under usual conditions these body fluids are in a state of incomplete saturation so far as calcium and phosphorus are concerned. Consequently, there is a constant dissolution of calcium and phosphorus from the resorbing surfaces even in growing bone. Bone deposition occurs in response to stresses and strains wherever bone is needed and also in the growing ends of long bones. This deposition consists in the laying down of an organic matrix or cartilage rich in phosphate due to the presence of osteoblasts. Phosphorylase, an enzyme present in growing cartilage and in bone tissue, is also important. This enzyme catalyzes the reaction in which inorganic phosphate is freed from organic esters. Thus, phosphatase and phosphorylase are responsible for increasing the concentration of phosphate ions on the surface where bone is forming. When the product of phosphate ions and calcium ions is sufficiently great, dahlite is deposited. This whole mechanism makes for efficient skeletal formation which is strong but not bulky. The factor, or factors, involved in the final limits of bone growth, which therefore limits stature, is not known, but some proposed theories will be discussed.

The calcium and phosphorus content of body fluids is of vital importance in bone growth. The calcium in serum is composed of three fractions: (1) calcium ions, (2) calcium bound to protein, and (3) a very small un-ionized portion in solution. Under normal conditions of protein content and hydrogen ion concentration, about 50 per cent of the calcium is in an ionized form in the serum. The phosphorus in the blood is con-

sidered by Albright to be under the influence of the parathyroid glands. An increased output of the hormone from these glands results in an increased urinary excretion of phosphorus. The serum phosphorus content decreases, and almost simultaneously the serum calcium level rises and the urinary excretion of calcium increases. This calcium is derived from bone. In normal circumstances the adjustment of the serum calcium to the serum phosphorus level is such that the product of the two, expressed as milligrams per 100 cubic centimeters is between 40 and 55 in growing children (30–40 in adults). This fact, plus clinical experience, is the basis for the law of Howland and Kramer which states that rickets will be present in children if the product is below 35 and that rickets will heal if the product rises above 40.

Bone growth, then, depends on the local condition of the tissues and the serum or body fluids which act as a substrate for the tissues. If some disturbance occurs to diminish the elaboration of the enzymes (phosphatase, phosphorylase), the concentration of phosphate ions will not be sufficient to exceed the solubility product of the complex calcium-phosphate-carbonate salt and deposition will not take place. However, even though the enzymes may be present in sufficient quantity, if the concentration of calcium or phosphate in the serum is low, the solubility product of the salt cannot be exceeded. Therefore, bone growth may be disturbed in two ways in the process of mineralization. Other factors, too, may interfere, such as poor matrix formation due to abnormality of protein metabolism. Finally, it is known that a lowered pH of the serum, as in chronic acidosis, favors decalcification by its effect on the ionization of calcium.

The clinical picture of hyperparathyroidism is characterized by decalcification of bone with resultant softening and malformation. Cysts may form in the bone and fractures occur. All of these may contribute to statural abnormality and relative dwarfism.

ADOLESCENCE AND PUBERTY

Adolescence is the "time of growing up." It lasts almost a decade and has no sharp beginning or end. It is the period of transition from childhood to adulthood. Puberty is a narrower span of time which marks the beginning of sexual maturation and occurs, usually, a little before the midpoint of adolescence. It should be recalled that growth is not complete until several years after full sexual development, but the final sharp ad-

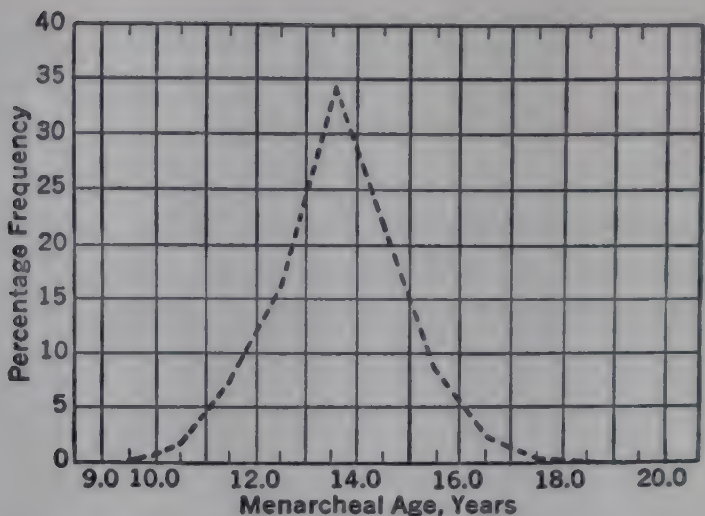

FIG. 47.—Average distribution of the time of onset of menarche in American girls. (Modified from Gould, H. N., and Gould, M. R.: J.A.M.A. 98:1349, 1932.)

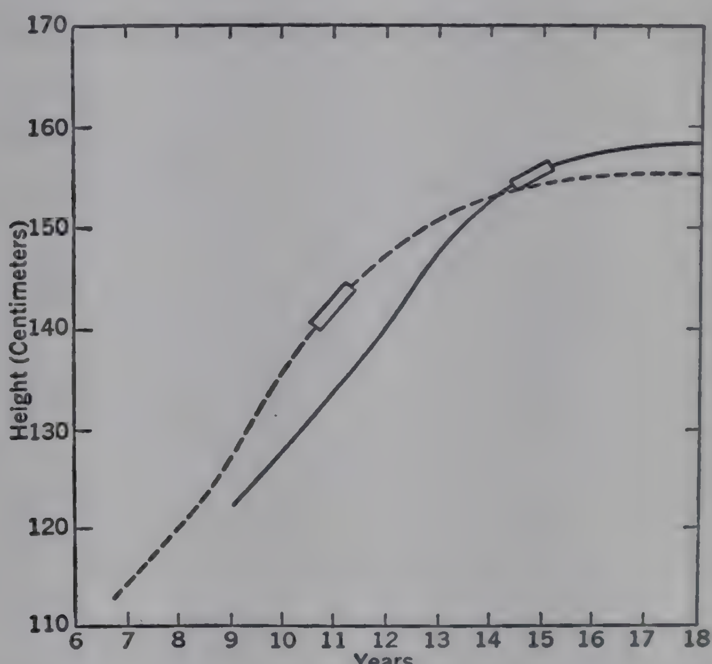

FIG. 48.—Relation of growth and onset of menarche. The blocks in the curves represent the time of menarche in two groups of girls. Girls with early menarche, and presumably reaching maturity early, have a more accelerated growth curve than girls with late menarche, but duration of their growth is shorter. As a result of this growth pattern, girls with late maturation are taller, on the average, when final stature is attained. (From Holt, L. E., Jr., and McIntosh, R. (ed.): *Diseases of Infancy and Childhood* [11th ed.; New York: Appleton-Century-Crofts Company, Inc., 1941].)

vance is followed by a marked deceleration and is apparently conditioned by the attainment of sexual maturity. This period is accompanied by psychologic as well as physical changes which are considered in other sections. In general, it may be stated that girls reach puberty about one to

three years sooner than boys. The menarche is often used as the dividing line between pre- and postpuberty in the female (Fig. 47). No such sharp division can be used in boys.

Generally speaking, the sooner puberty occurs the sooner will the rate of growth decline and finally stop.[27] This can be nicely shown in girls by charting two subjects on the same graph. If the onset of menarche occurs earlier in one, her growth curve levels off sooner than that of the

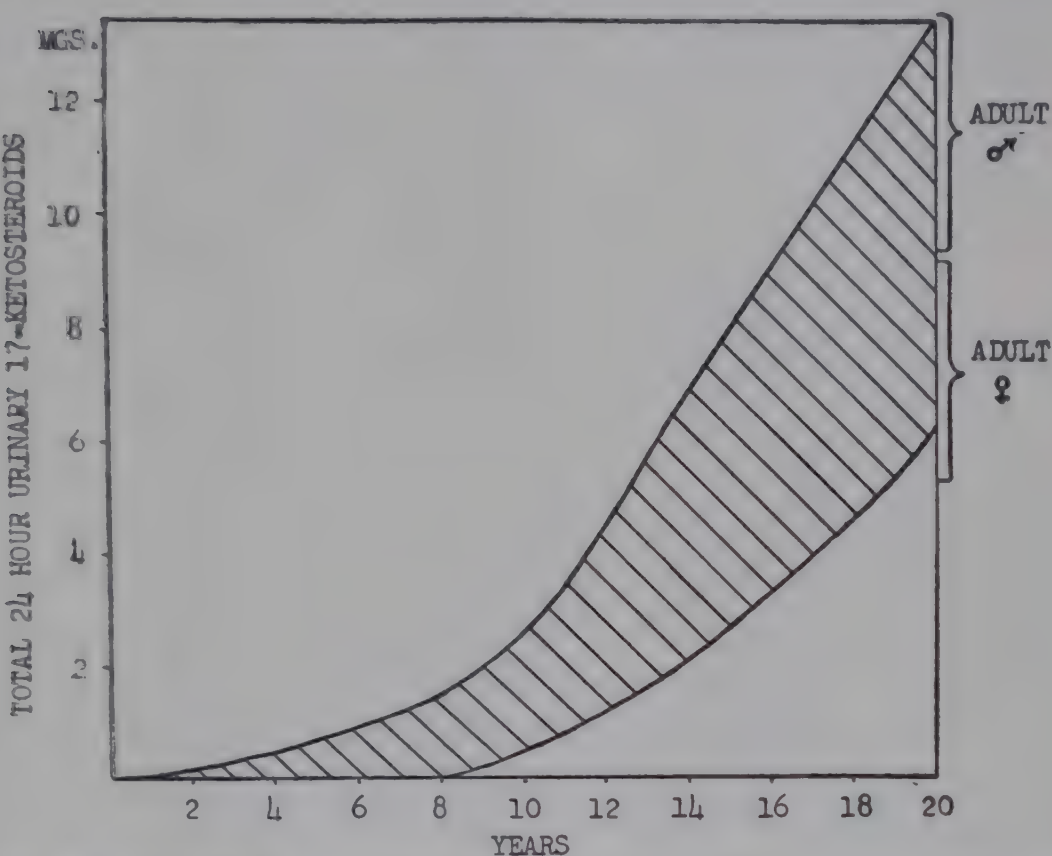

FIG. 49.—Excretion of 17-ketosteroids at different ages. (Modified from Talbot, N. B., *et al.*: Am. J. Dis. Child. 65:364, 1943.)

other subject under study. This growth curve may be representative of height, weight or of body dimensions in general (Fig. 48). The mean height and weight of boys or girls who are more mature sexually are significantly greater than those who are less mature, and the onset of puberty is better correlated with these measurements than with chronological age.[6]

Hormonal assays used in studies on puberty have yielded much valuable information. From determinations of secretion of the gonadotrophic hormones of the anterior pituitary it is obvious that some rise in their secretion takes place several years before puberty, for at that time they can

be detected in the urine of both boys and girls. From this it would appear that, preceding puberty, there is an increase in the gonadotrophic hormone output with a consequent stimulus to the sex glands.[17, 31]

Between the ages of 3 and 7 years the urine of both boys and girls contains the 17-ketosteroids and estrogens in equal amounts. At about 8 years of age the excretion of both of these products begins a gradual but steady rise. Between 9 and 11 years there is a more dramatic rise in the excretion of 17-ketosteroids; the rise is slightly greater in boys than in girls. In boys the increased excretion of these substances coincides with the

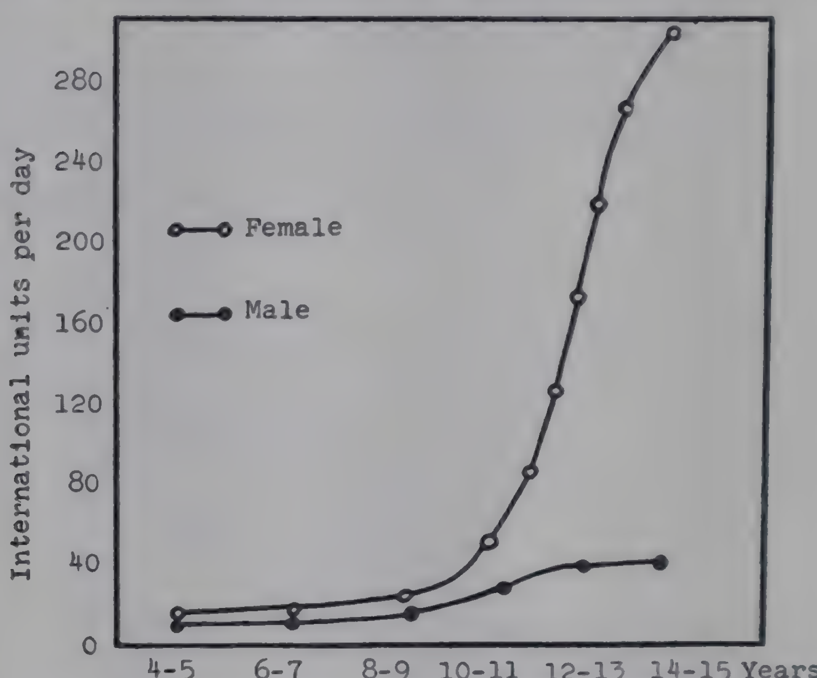

Fig. 50.—Excretion of estrogen at different ages. (Based on the figures of Nathanson *et al.*[17])

increase in size of the testes and the initial appearance of secondary sex characteristics. In girls there is a continued gradual rise in the ketosteroid excretion throughout puberty (Fig. 49).

The fact that both boys and girls secrete nearly equal amounts of androgens during the prepubertal period suggests that their source is not the gonads but probably the adrenal glands.[13] The later increase in androgen secretion in boys and estrogen secretion in girls parallels sex gland maturation. To support this theory, we know that with pathologic hyperfunction of the adrenal gland, as well as of the gonads, there may be a very high androgen excretion.[18, 29]

Estrogen excretion in boys continues at a fairly low level, but in girls the excretion rate increases at the age of 8–9 years, followed by a

markedly accelerated rate throughout adolescence (Fig. 50). At the beginning of this increase one sees the differential development of the female pelvis and other sex changes which characterize the onset of puberty. Following this period the estrogen excretion becomes cyclic, with

TABLE 33.—AVERAGE WEIGHT (GM.) OF ENDOCRINE GLANDS AND SOME SEX ORGANS AT VARIOUS AGES*

	NEWBORN	1 YR.	6 YR.	PUBERTY	ADULT
Pituitary	0.1	0.2	...	0.6	0.6–0.8
Thyroid	1.5–2.5	3.0	8	25	30–40
Adrenals (2)	6–8	4.5	7	...	10–12
Parathyroids	...	...	...	...	0.65
Testes (2)	2.0	...	4.0	20	50
Ovaries (2)	0.3	1.0	...	4–6	7.5
Uterus	3.2	2.0	...	8	27
Prostate	...	...	1.8	...	20

*From several sources.

a rise in urinary estrogen excretion preceding the beginning of menstruation; and it is at this time that the accessory organs, such as the uterus, develop rapidly[17] (Table 33).

The sudden burst of growth preceding puberty is almost certainly under the influence of the sex glands. In mammals, growth is inhibited by administration of estrogen in large doses and consequent anterior pituitary hypertrophy. Androgen in large amounts also inhibits growth, but in low doses may be stimulating to the anterior pituitary and secondarily to growth.[31] The smaller size of the female among mammalia may be related to the inhibition of growth and to early puberty caused by estrogens and the greater size of the male to the stimulation of growth by androgens.

In addition to the changes already recorded, there is frequently seen at puberty a rather pronounced enlargement of the thyroid gland due to hypertrophy and hyperplasia of the acini (Table 33). Normally, this is followed by involution of the gland to its former status, but occasionally the clinical picture of true hyperthyroidism results, with all of its manifestations, including exophthalmos. The cause of these changes is not known, but the pituitary is believed by many workers to be the source of these phenomena through excessive secretion of the thyrotrophic factor. Colloid or iodine-deficient goiter is also more common at this time, particularly in girls.

The genetic factor in growth and sexual development is extremely important but not clearly understood. There are definite familial tend-

encies to early or late onset of adolescence. In many cases of delayed or precocious puberty the genetic factor seems to be the only possible explanation for divergence from the usual pattern. Wilkins[34] has stated that the majority of patients coming to his endocrine clinic with disturbances of growth or sexual development present genetic, not endocrine, problems.

Finally, one must also consider the neurogenic factors in sexual growth. The hypothalamus in particular is known to have some influence over the pituitary. With Fröhlich's syndrome, due to lesions of the brain (hypothalamus), there is sexual infantilism. Conversely, lesions in the same (?) region may produce marked sexual precocity.[10] The explanation of this apparent incongruity seems to lie in the fact that lesions near the pituitary or involving controlling centers of the brain may either stimulate or depress pituitary activity, depending on several variables. In fact, a given tumor of the hypothalamic area may first stimulate and later destroy the pituitary or certain nerve tracts, thus causing at different times exactly opposite clinical effects.

The influence of the endocrine glands on the ultimate stature of human beings depends on several factors. The inhibiting action of estrogens and promoting action of androgens relative to stature have been mentioned. The fact that eunuchs usually stop growing at the time puberty would normally occur suggests that secretion of the pituitary growth hormone diminishes or ceases spontaneously at about this period. The failure of acromegaly to develop in normal adults also lends support to this hypothesis. Finally, complete epiphyseal maturity precludes further growth. This process of maturation has been shown to be influenced by the thyroid, the estrogens and the androgens, the latter two probably being most significant as puberty is reached.

The development of secondary sexual characteristics usually follows a fairly set pattern, although there may be considerable individual variation (Table 34).[21, 24, 28] Many have observed that the development of sexual characteristics is much more closely correlated with bone maturation than with chronological age. There is likewise a better correlation between maturation and measurements of height and weight than with age. Enlargement of the breasts and rounding of the contours of the hips are the first discernible changes in girls. Accumulation of subcutaneous fat in girls may be noted in the regions of the thighs, buttocks, chest, lower abdomen and the mons veneris. By the time of menarche the small budding breasts have progressively enlarged to assume a conical shape. The

mature or rounded form gradually develops during the next two to four years. The first appearance of pubic hair precedes menarche by a year or more; it becomes more deeply pigmented and coarser throughout adolescence and into adult life. The initial growth of axillary hair may follow menarche or occur shortly before it.

In boys a slight hypertrophy of tissue around the areolae of the breasts appears, on the average, about two years later than similar changes in girls. As adolescence advances, an involution of this tissue takes place and breasts of the adult type result. Pubic hair first appears with the beginning

TABLE 34.—Average Time of Appearance of Primary and Secondary Sexual Characteristics in American Boys and Girls*

Characteristic	Girls	Boys
Pelvis	Female contour, fat deposition, begin at 8–10 yr.	
Breasts	Increase in size begins at 9–11 yr.; histologic maturity at 16–18 yr.	
Vagina	Secretion begins, glycogen content of epithelium increases at 11–14 yr.	
Penis and testes		Increase in size begins at 10–12 yr.
Pubic hair	9–11 yr.	10–12 yr.
Axillary hair	10–13 yr.	10–14 yr.
Facial hair		12–15 yr.

*From several sources.

increase in size of the penis. Axillary and facial hair come shortly thereafter. Puberty is said to be reached in the male when the pubic hair becomes darker, coarser and begins to curl. Other body hair in the male undergoes similar changes, but these are much later and continue well into adult life. The characteristic hairline on the forehead in men is one of the last developments of sex maturation. Deepening of the voice, due to growth of the larynx in the ventrodorsal diameter, occurs at mid-adolescence (average 14–16 years) in boys.[21]

Some changes that take place are common to both the female and the male body. There is increased development of the glands of the skin, both apocrine and sebaceous, most marked in the axillary, circumanal and labial areas. Pigmentation of the skin in these regions (and of the male sex organs) also takes place and is more pronounced in the male. Muscular development progresses rapidly in both sexes, but obviously is more pronounced in males. The involution of the lymphatic system begins at this time and continues for several years. Finally, differences in the red blood cell counts and hemoglobin values may be noted (Tables 20 and 21, pp. 155 and 154).

Acne is so common during the adolescent period that it has come to be regarded by some as physiologic rather than pathologic.[11] It is present to some degree in 75–90 per cent of children before 18 years of age. The primary lesion is the plugged sebaceous gland or comedo. When it becomes secondarily infected and a pustule forms the condition is termed acne. That there is a definite relation to the sexual changes of adolescence seems convincing. It does not develop in eunuchoid individuals at any age unless adequate substitution therapy with androgens is administered. Withholding of therapy results in clearing of the lesions. The appearance of acne in small children with the adrenogenital syndrome is associated with a high excretory titer of androgens. Furthermore, it has been shown that androgens cause an increase of sebaceous secretion. However, in some individuals there is an apparent predisposition to acne, and in the more severe forms this is probably an important factor.[11]

TABLE 35.—Pathologic Conditions Associated with Abnormalities of Sexual Development*

Conditions associated with *delayed onset* of puberty
- Pituitary dwarfism
- Hypothyroidism
- Hypogonadism (agenesis, atrophy, surgical or traumatic castration)
- Acromegaly (rare)
- Any severe chronic illness
- Hypothalamic lesions (Fröhlich's syndrome)

Conditions associated with *precocious* sexual development
- Adrenal cortex tumors or hyperplasia (pseudohermaphrodism in girls)
- Interstitial cell tumors of the testes
- Ovarian tumors (granulosa cell and thecoma)
- Basophilic tumor of the pituitary (pseudohermaphrodism in girls)
- Pineal gland tumors (in males only)
- Third ventricle tumors of the brain
- Hydrocephalus (rare)
- Post-encephalitis (rare)
- McCune-Albright syndrome (polyostotic fibrous dysplasia)

*Besides the endocrine glands, it will be noted that the central nervous system (hypothalamus) may also be involved.

Some descriptions have already been given of the development of the primary sex organs. A few additional statements are necessary. The vaginal mucosa changes from columnar to squamous shortly before menarche.

Concurrent with this change there is an increased glycogen content of the mucosa and the pH becomes lowered. As a result, the bacterial flora of the vagina changes. It is probable that during the first one or two years following menarche the menstrual periods of most girls are anovulatory. The first several menses are often irregular and the interval is longer or shorter than is characteristic of later life.[20, 22]

The many changes associated with adolescence apparently alter some of the body's defense mechanisms against disease. The susceptibility to tuberculosis is higher at this age period than at any other. The incidence of rheumatic fever sharply declines after puberty is reached. With regard to these diseases, one must not ignore the increased exposure factor which is usually concurrent at this age. Thyrotoxicosis, particularly in girls, is more common during this period of life than in any other single age span. The importance for the adolescent of adequate nutrition in maintaining development and in preventing disease has been stressed.[12] Further discussion of this subject will be found in Chapter 11.

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10

Energy Metabolism

THE KNOWLEDGE OF METABOLISM in infants and children has been used as a practical tool in studies of nutrition such as determining caloric requirements, establishing or ruling out such diagnoses as hypothyroidism, hyperthyroidism, mongolism and simple obesity, defining optimal conditions of environment for newborns and prematures, establishing better norms for growth and development and, finally, improving understanding of the processes of living matter.

Heat is produced in all tissues of the body by oxidative and nonoxidative reactions. Skeletal muscle produces the largest portion, even during rest. When external temperature is markedly reduced, the muscles are called upon to produce more heat by shivering. The liver produces more heat than any other internal organ, about 20 per cent of the total body heat at basal levels. All growing organisms, whether unicellular or multicellular, produce heat, and this is a function of growth. From infancy to adolescence heat production by the body is in a dynamic state, but after the completion of growth it is relatively static.

TEMPERATURE REGULATION

Temperature regulation is obviously essential to man because wide variations, no matter what the etiology, may cause death. This subject is of vital importance in the study of metabolism.

Heat is lost from the body of an adult[3, 12] by:

Radiation, conduction and convection	70%
Evaporation (skin and lungs)	27
Warming inspired air	2
Urine and feces	1
	100%

The same values for heat loss by evaporation have been found in the newborn and premature.[7] These factors are influenced by environment, such as air temperature, humidity, clothing and metabolism. Body control of these factors is through:

1. Redistribution of blood: vasodilatation and constriction influencing skin temperature.
2. Variations in blood volume: rise in temperature causes an increase from tissue fluid dilution of the blood.
3. Secretion of sweat and exhalation of water vapor.
4. Metabolism: the metabolic rate rises when environmental temperature falls much below body temperature. Shivering, already mentioned, is one factor which may cause an increase of 180 per cent in the rate over basal levels.

The regulatory centers for temperature control are located in the hypothalamus and are apparently influenced reflexly by skin temperature and by temperature of the blood flowing through them. The thyroid gland and adrenals also play a role in regulating heat production. Removal of either or both causes a lowering of body temperature, whereas administration of thyroid extract or epinephrine increases metabolism and raises body temperature. In cretins and in patients with Addison's disease the body temperature is low.

In the newborn the mechanisms of sweating and shivering are imperfectly developed. Added to this is the relatively large surface area with a meager amount of subcutaneous fat and resultant poor insulation. These all contribute to the relative instability of body temperature typical of the neonatal period. At the time of birth the infant has about the same temperature as his mother. Immediately, the temperature falls, regardless of the means taken to protect against it. In an average nursery where the room temperature was kept between 80 and 85 F., there was a drop of 3° F. in the first hour (average for 20 infants).[13] The maximal drop was 4.6° F. by the third hour. The rise from this low point is gradual, and a few or many hours may be required for return to the so-called "normal" body temperature. Such rapid recovery would hardly seem to indicate physiologic immaturity of the brain center as Talbot has indicated.[14] Crying by the newborn is, in part at least, a defense mechanism to increase his body temperature through a step-up in metabolism; in some infants the increase in rate may be as much as 180 per cent over the basal level. The newborn baby also has a relatively poor ability to resist very high environmental tempera-

tures since sweating does not become a dependable means of losing body heat until the infant is about a month old.[13] In general, the more mature the baby, the greater the birth weight, the less the probable fluctuation in body temperature.

In the premature infant the skin and internal (rectal) temperatures parallel each other closely and fluctuate widely with extremes of environmental temperature. The smaller the premature, the less able he is to maintain body heat by shivering or by vasomotor responses of the skin. Similar studies of the mature infant show less fluctuation of skin temperature, and the internal temperature remains more nearly constant throughout fluctuation of environmental temperature.[13] These facts clearly show the relatively inefficient performance of the premature as compared with the older baby. It is also known that premature babies at room temperature of 80–85 F. and humidity of 60 per cent keep a more constant body temperature, though it may be slightly below "normal" (95–98 F. per rectum), than if the room temperature is 90–95 F. Whether the relatively low body temperature causes any harm when maintained for long periods of time is not known; however, weight gain has been observed to be satisfactory in nearly every instance. These "subnormal" temperatures may actually aid the premature infant by reducing his metabolism and therefore the food requirements and digestive processes.[4, 7, 13]

In brief, the physiologic basis for faulty control of body temperature of premature infants is:

1. A low total heat production dependent on body inactivity and feeble musculature.
2. A surface area out of proportion to weight.
3. A paucity of insulating fat.
4. An immature sweating mechanism.
5. An inadequate nervous control (postulated).

RESPIRATORY METABOLISM

"Metabolism is the term employed to embrace the various chemical processes occurring within the tissues upon which heat production and growth of the body depend and from which the energy for muscular activity and for the maintenance of vital function is derived."[3] Heat produced by an animal is largely the result of oxidation of foodstuffs, and by measuring the oxygen consumed one can compute the metabolism of the body.

The respiratory quotient (R. Q.) has an important bearing on many phases of metabolism. It is the ratio of the volume of carbon dioxide produced to the volume of oxygen used: R.Q.$=CO_2/O_2$. For the complete combustion of carbohydrates the respiratory quotient is 1.0. For fat the value is 0.71 and for protein 0.80. Thus the respiratory quotient can be taken as an indication of the type of food being metabolized by the organism. In man, on a mixed diet, the quotient is around 0.85. A diet high in carbohydrates will raise it, and a diet high in fat will lower it.*

Careful studies of the respiratory quotient in the newborn have, in general, revealed high values for the first day. For three or four days after birth there is a drop to rather low levels, followed by a rise to near

TABLE 36.—Changes in Respiratory Quotient in the Newborn

		% of Total Energy from	
Day of Life	R. Q.	CHO	Fat
1st few hours	0.90	66	34
1	80	30	70
2	74	8	92
3	73	5	95
4	75	12	88
5	79	26	74
6	82	38	62
7	81	34	66
8	81	34	66

the adult quotient. These figures give good evidence that during the first day of life carbohydrate is used almost exclusively as the source of energy. The stores of glycogen are soon exhausted, and until breast milk or a formula is taken well, by the fifth and sixth day, fat is utilized for energy needs. This reasoning is substantiated by the observation that the blood sugar content of the newborn is quite low and for a brief period remains low. Table 36 shows this rather dramatic change in the respiratory quotient for the first few days of life.[13]

In general, the respiratory quotient for premature infants remains low for a longer period and then rises to a slightly higher level than does that of a more mature infant.[4, 13]

To maintain basal needs of about 1.7 calories per kg. (0.8 calories per lb.) per hour and, in addition, to provide an allowance for activity, growth, fecal loss and specific dynamic action, the total food requirement is estimated as 80 calories per kg. per day (36 calories per lb.). However, the

*The R. Q. for a premature or newborn may not truly reflect the source of energy being used, for in both, anaerobic metabolism may form some considerable part of the heat production mechanism.

spontaneous intake of newborns to the point of satiety by the first day averages 90 calories and by the eleventh day over 100 calories per kg.[13] When a proper caloric intake is being estimated the baby's activity must be considered. It has already been pointed out that strenuous crying may increase the basal level of metabolism by 180 per cent, so a very active infant will require a higher caloric intake than one who is more lethargic.

The premature infant has a greater requirement, estimated as high as 150 calories per kg. However, Levine and Gordon[7] have shown that

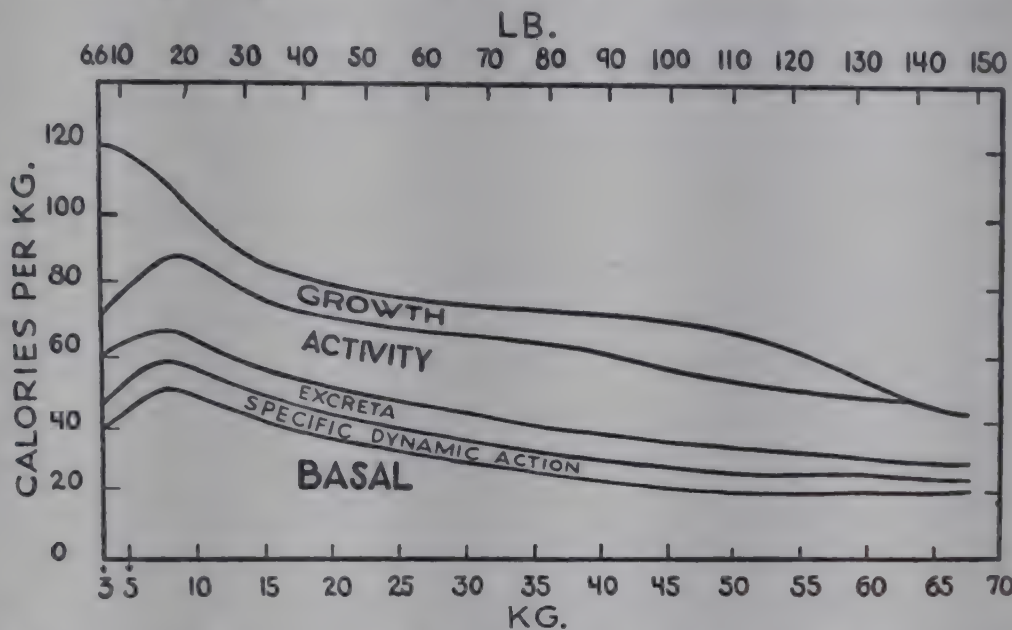

FIG. 51.—Caloric requirements of boys during growth. The space between the various curves indicates the average allowance for the various factors which make up the total required number of calories per kilogram of body weight. (From Holt, L. E., Jr., and McIntosh, R.: *Diseases of Infancy and Childhood* [11th ed.; New York: Appleton-Century-Crofts Company, Inc., 1941].)

120 calories per kg. (55 calories per lb.) in a low fat formula produced excellent results and adequate weight gain when given after the fifth to eighth day of life.

Figure 51 shows the relative caloric requirements during the period of active growth.

BASAL METABOLISM IN CHILDREN

It will be readily realized that in infants and small children many of the criteria cannot be met for a true basal metabolic rate, e.g., fasting conditions, no muscular activity and other factors inherent in a true basal condition. However, we can obtain nearly basal levels and the lacking factors can be considered in the final evaluation. As in an adult, a single reading has little value, but repeated recordings may be of considerable

aid. In infants and children under 4–5 years, the chamber method or direct calorimetry must be used.

Norms of metabolism can be presented only in terms of averages, for the metabolism of the great majority of individuals does not agree exactly with any accepted standard. The following factors, responsible for variations from the normal, must be carefully evaluated.

1. *Pulse rate.*—Muscular exercise is usually accompanied by an increase in the pulse rate and heat production.

2. *Climate.*—Hot weather usually reduces body heat production; the converse is true of cold weather.

3. *Growth.*—The two stages of rapid growth in childhood, during the first year of life and at puberty, are associated with a greater relative heat production than at any other time. This "growth factor" is most important in comparisons of metabolism of children and adults. The complexities of the relationship of growth and metabolism are not well understood, but we do know that the rate of growth does not necessarily correlate well with the various changes in metabolism. (See also paragraph 5.)

4. *Food intake.*—An insufficient diet causes not only a loss of weight but a lowered metabolic rate. In a normal individual the ordinary mixed diet raises the metabolic rate about 6 per cent above the basal level; overfeeding may raise it as much as 40 per cent. This factor, called specific dynamic action, must be considered in the nonfasting child. However, Murlin[11] stated that in children under 1 year of age an average feeding increased metabolism very little or none at all over basal levels. In infants fed milk with a very high protein-content (40 per cent of the total caloric intake) the metabolic rate may increase as much as 25 per cent. This condition is, of course, rarely to be considered.

5. *Age*—This is a most important factor for the pediatrician. The younger the individual, the greater will be the tendency to variation from the average. Heat production increases with increasing age so long as growth continues; thereafter is a period of relative stability corresponding to active maturity, and finally a definite decline which begins about the fifth decade.[1, 3]

PREMATURE INFANTS.—During the first few weeks of life the heat production of the premature may be very low (between 46 and 92 calories for 24 hours). On the basis of body surface, the averages are generally lower than those for a mature newborn. Further, the premature infant may produce less heat on his expected birth date than does the full term infant

during any day of his first week of life. Activity, when manifested by a premature, increases the heat production above the basal level by an average of 40 per cent, compared with 65 per cent for the normal newborn. Until height and weight are normal for age, the metabolic rate of the premature remains below that of the normal infant.[7, 13]

FULL TERM INFANTS.—Depending on the weight of the baby, his vitality and the amount of fat tissue present, the average figures range from 125 to 165 calories produced per 24 hours. It is interesting to note that the smallest baby does not necessarily produce the least amount of heat. For a fairly large series of infants, the average figure was 42 calories per kg. per 24 hours, or about 28 calories per sq. m. per hour. Judged by weight, the infant at birth is more active metabolically than is the adult but less so than the child of 1–3 years of age.

OLDER INFANTS AND CHILDREN.—All the data thus far obtained tend to show that physical development rather than age determines the metabolic rate. Not all observers agree that there is a rise of metabolic rate at the onset of puberty, and the relation of the endocrine glands at this time is not clearly understood with respect to metabolism. Talbot and his co-workers[14] have been unable to demonstrate any definite change in the B.M.R. at puberty. However, Lewis *et al.*[8] noted a relative increase at the prepubertal ages, i.e., a brief period of leveling off between the twelfth and the fifteenth year. Incidentally, this period did not coincide with the period of most rapid growth, but it did parallel the period of increased gonadal activity as measured by hormone excretion.[9] In a small series of girls on whom metabolic readings were done at frequent intervals Johnston[6] demonstrated that there was a relatively sharp rise in B.M.R. at the time of menarche, followed by a transient fall. Coincident with these changes there was a high retention of calcium and nitrogen before menarche, followed by a transient depression of retention of these substances. The use of different standards by the several authors only adds confusion to an already confused picture. Table 33 shows the relative metabolic averages for premature and term newborns and adults based on different standards.

6. *Sex.*—Until age 8 there is only a slight difference between the sexes. At approximately this time boys have a slightly higher rate than girls. The rise at puberty, when present, occurs about two years sooner in girls than in boys. At the end of the second decade of life there is usually more than 10 per cent difference in favor of the males.

The selection of the most ideal standards for children has been an important part of the studies of metabolism in pediatrics. Especially in younger children, the DuBois body surface method has proved unsatisfactory. Talbot[16] carefully worked out standards based on height and weight and largely ignored age and surface area as standards to be used routinely. In this regard it is known that small human beings have greater surface areas in comparison with their weight than do larger subjects. For instance, the newborn has 16 per cent as much surface area as adults, but weight is only 5 per cent that of adults. Talbot believes that the heat production "regulator" is the active mass of tissue in the infant's body, that is, muscle.[14] To substantiate this theory, Talbot and his co-workers[18]

TABLE 37.—Average Basal Metabolic Rates for Premature and Term Newborns and Adults According to Different Standards*

	Total Basal, per hr.	Av. Calories per sq.m./hr.	Av. Calories per kg./hr.
Premature infants	6.48	26.25	2.04
Term infants	6.67	29.16	2.00
Adults	. . .	35–40	1.00

*From Smith.[13]

showed that there is a good correlation between creatinine excretion and total basal caloric output. However, to use creatinine excretion as a standard for metabolism is impractical owing to the difficulty in collecting 24 hour urine specimens and the necessary laboratory procedure.

Lewis *et al.*[9] found the following formulas most satisfactory in attempting to predict expected metabolic rate: for boys, cal./sq.m. $= 1.20 \times$ years of age $+ 56.70$; for girls, cal./sq. m. $= 1.38 \times$ years of age $+ 55.36$. In a large series of determinations on subjects of average height and weight for age, they found that the lowest degree of scatter occurred when the B.M.R. was based on weight or surface area and the least correlation when age was used as a standard. Benjamin and Weech[2] obtained similar results on infants from 6 to 20 months of age.

Wetzel[19] has advocated using "developmental level" as the most satisfactory standard for basal heat production. By use of the Wetzel grid the developmental level can be plotted and the normal heat production is then read from one of the ordinates of the auxodrome (Fig. 5, p. 67). Wetzel and others who have used this method claim considerable accuracy for it.

Figures 52–55 and Tables 37–40 illustrate the various standards used and the results obtained from some of the more complete studies.

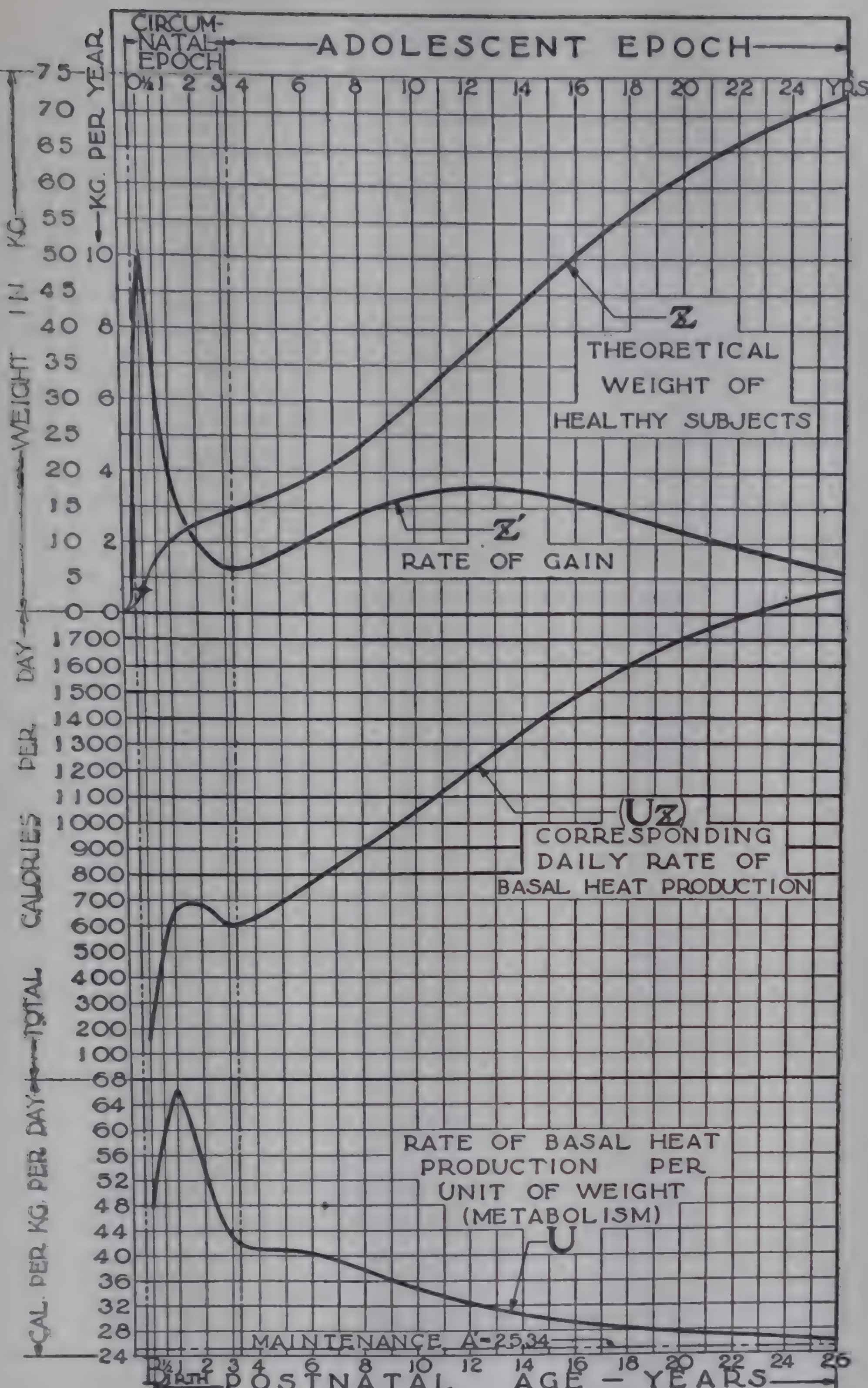

FIG. 52.—Curves comparing growth and heat production. All curves are plotted against a common abscissa, age. Ordinates for each curve are different, and are properly indicated. For Z the ordinate is weight in kg.; for Z', kg./yr. All curves are based on averages. Note that the curves for theoretical weight and daily rate of basal heat production follow similar patterns, lending support to the selection of weight as the most suitable criterion for the basis of energy (metabolism) studies during

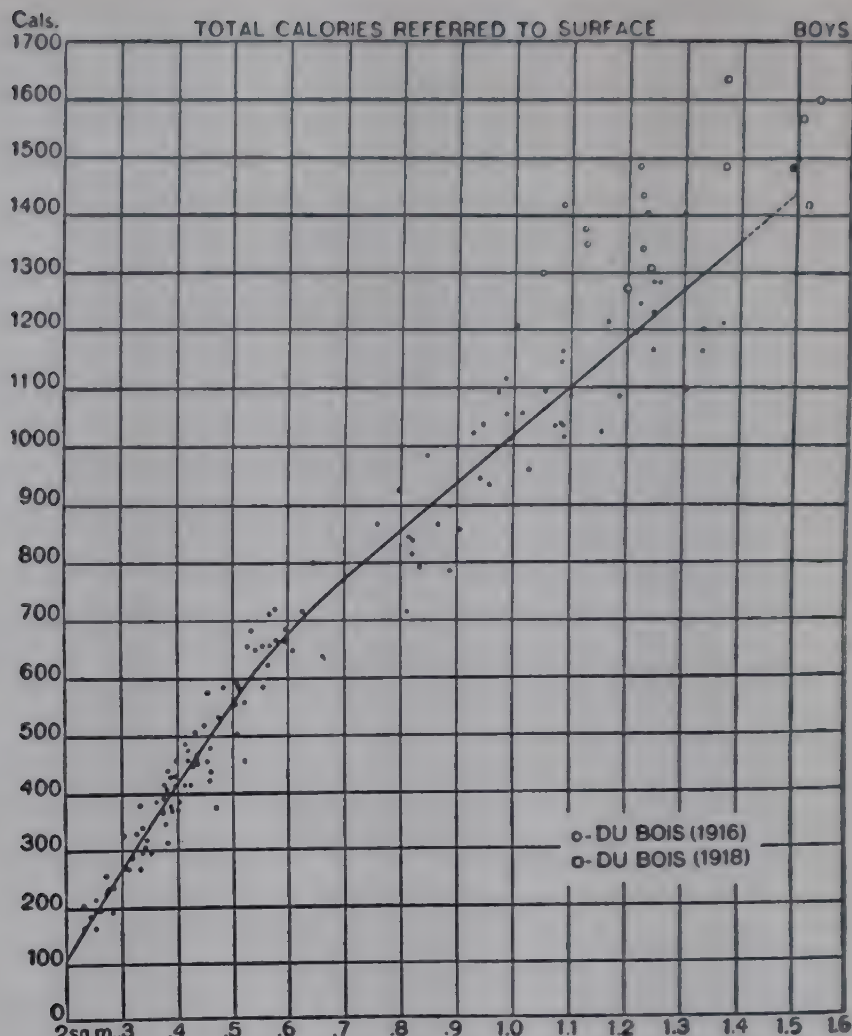

FIG. 53.—Metabolism curve for boys based on total calories produced at basal levels referred to surface area (sq. m.). (From Benedict, F. G., and Talbot, F. B.: Carnegie Inst. of Washington Pub. no. 302, 1921, p. 161.)

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growth. The curves also show that heat production and growth are so closely related as to be part of the same biologic processes. Birth occurs at the peak of the curve for "rate of gain" under normal conditions; the premature must attain this peak in the less favorable conditions of extrauterine existence. Some difficulties of rearing premature infants can thus be attributed to stresses of growth in a relatively adverse environment. Note also that between 3 and 4 the average child has reached a low point in rate of gain, a leveling off of theoretical weight and a relative decrease in heat production (whether measured as total calories or based on unit of weight). In this period, physiologic anorexia is common. Curve *U* is said to represent true metabolism. The high metabolism of infants is ascribed to "cellular synthesis" and "heat of dissipation" by Wetzel, or to the rapid growth and differentiation that take place during these years. Even during the prepubertal spurt of growth this curve undergoes a steady decline, reaching its lowest level when growth ceases. (From Wetzel, N. C.: J. Pediat. 4:484, 1934.)

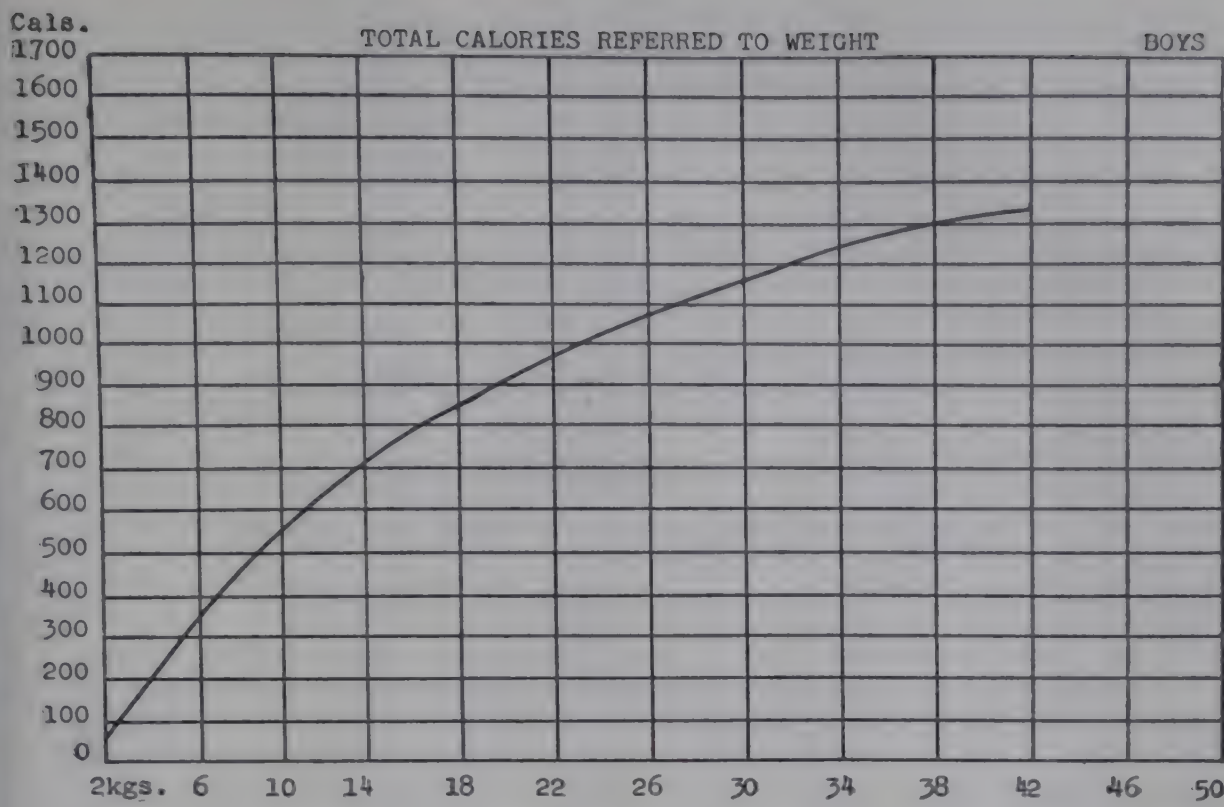

Fig. 54.—Metabolism curve for boys, based on total calories produced at basal levels referred to weight. (From Benedict, F. G., and Talbot, F. B.: Carnegie Inst. of Washington Pub. no. 302, 1921, p. 143.)

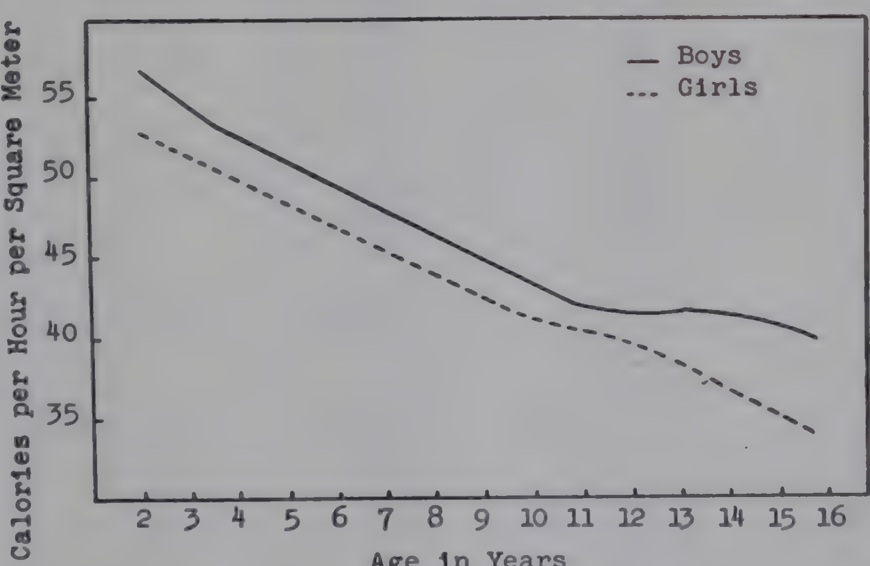

Fig. 55.—Metabolism curves for boys and girls, based on calories produced per hour per square meter referred to age. Note particularly the tendency to a leveling off in the prepubertal years. (From Lewis, R. C., *et al.*: Am. J. Dis. Child. 66:296, 1943.)

TABLE 38.—RESULTS PICKED AT RANDOM SHOWING GENERAL TRENDS OF B.M.R. FOR NORMAL SUBJECTS*

Age	Weight, Kg.	Heat/24 Hr.	Heat/Sq.M./Hr.	Heat/Kg./Hr.
2 days	3.45	162	32.1	1.91
5 days	3.34	150	30.5	1.88
6 mo.	5.40	353	40.0	2.75
10 mo.	9.37	479	37.7	2.12
2½ yr.	11.5	585	51.9	2.20
5 yr.	15.5	720	52.4	2.01
9 yr.	22.0	898	44.9	1.70
10 yr.	30.6	1,065	41.3	1.43
14 yr.	40.2	1,300	39.2	1.35
18 yr.	65.6	1,700	32.8	1.08
Adult	70.0	1,400†	35–40.0†	1.00†

*Mainly from data of Lewis, Murlin and Talbot.
†Average figures.

TABLE 39.—STANDARD TOTAL CALORIES FOR WEIGHT*—GIRLS AND BOYS†

Weight, Kg.	Total Calories per 24 Hr.		Weight, Kg.	Total Calories per 24 Hr.	
	Girls	Boys		Girls	Boys
3.0	136	150	36.0	1,173	1,270
4.0	205	210	38.0	1,207	1,305
5.0	274	270	40.0	1,241	1,340
6.0	336	330	42.0	1,274	1,370
7.0	395	390	44.0	1,306	1,400
8.0	448	445	46.0	1,338	1,430
9.0	496	495	48.0	1,369	1,460
10.0	541	545	50.0	1,399	1,485
11.0	582	590	52.0	1,429	1,505
12.0	620	625	54.0	1,458	1,555
13.0	655	665	56.0	1,487	1,580
14.0	687	700	58.0	1,516	1,600
15.0	718	725	60.0	1,544	1,630
16.0	747	750	62.0	1,572	1,660
17.0	775	780	64.0	1,599	1,690
18.0	802	810	66.0	1,626	1,725
19.0	827	840	68.0	1,653	1,765
20.0	852	870	70.0	1,679	1,785
22.0	898	910	72.0	1,705	1,815
24.0	942	980	74.0	1,731	1,845
26.0	984	1,070	76.0	1,756	1,870
28.0	1,025	1,100	78.0	1,781	1,900
30.0	1,063	1,140	80.0	1,805	....
32.0	1,101	1,190	82.0	1,830	....
34.0	1,137	1,230	84.0	1,855	2,000

*Calories produced under basal conditions compared to weight.
†From Talbot.[38]

If physical development is average, the number of calories produced per kilogram will equal that of normal children of the same age, sex and physique. If the proportion of inactive body substance is small (fat, bone and body fluids), the caloric output per unit of weight will be greater. Conversely, if there is a greater amount of inactive tissue, as in obese children, the number of calories produced per unit of weight will be less than the average. When data obtained from obese but otherwise normal children were compared with body surface as one standard and height-weight as the other standard, the difference between the sets of figures amounted to over 25 per cent in many instances.[14] This demonstrates the difficulty in choosing the proper yardstick for measurement.

TABLE 40.—STANDARD TOTAL CALORIES FOR HEIGHT* (OR TOTAL CALORIES FOR EXPECTED WEIGHT)—GIRLS AND BOYS†

Height, Cm.	Total Calories per 24 Hr. Girls	Boys	Height, Cm.	Total Calories per 24 Hr. Girls	Boys
48	134	...	92	681	725
50	159	...	94	695	740
51	...	160	96	709	755
52	186	175	98	722	765
54	214	200	100	735	785
56	246	225	105	770	805
58	278	260	110	807	830
60	309	300	115	846	875
62	341	315	120	894	935
64	373	360	125	942	990
66	404	390	130	987	1,045
68	433	420	135	1,057	1,105
70	462	450	140	1,130	1,165
72	489	480	145	1,208	1,220
74	515	510	150	1,294	1,290
76	539	535	155	1,386	1,380
78	560	565	160	1,477	1,480
80	581	590	165	1,544	1,570
82	601	612	170	1,584	1,655
84	619	635	175	1,596	1,720
86	636	660	180	1,600	1,800
88	652	685	190	....	1,900
90	666	705			

*Calories produced under basal conditions compared to height. Since the height standard is based on a normal weight, this can also be called expected weight.
†From Talbot.[16]

Determination of metabolism must take into account all of the factors previously considered. The following quotation is from Talbot's discussion of metabolism in children. "First of all, a visual and tactile estimation is made of nutrition, muscle tone and appearance of the patient. The stage

of skeletal development and nutrition is estimated by comparing the actual height and weight with the average given for sex and age. If the clinical impression is correct, metabolic findings should follow certain expected trends determined by the proportion of physiologically active and inactive body tissue."[14] Thus, in obese children results based on height and weight for age will probably give truer results than those based on actual weights or on body surface. The normal limits arbitrarily set up by most workers in this field are plus or minus 15 per cent on repeated and carefully controlled tests. Finally, it must be fairly stated that at present no standards are universally accepted and none has been advocated which is completely free from faults. On many occasions the measurement of the B.M.R. may be of value, but too much reliance should not be placed on such a procedure when it is used alone.

A single example may be cited to demonstrate the difficulty in properly evaluating standards. Three satisfactory determinations of oxygen consumption were obtained on an 8 year old boy who was slightly obese but otherwise normal. Basal metabolic rate, determined according to the different standards, was:

Standard of Comparison	B.M.R.
Body surface (Mayo Clinic)	−19%
Height (Talbot)	+10%
Expected weight for age (Talbot)	− 5%
Wetzel grid	−10%

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11

Nutrition in Normal Growth

The infant and child must have food for growth and for maintenance and repair of body tissues. We know that to supply the caloric requirement alone is not sufficient to promote optimal growth, for we must consider quantitatively the basic foodstuffs—protein, carbohydrate, fat, minerals and vitamins. In this chapter we do not propose to describe in a practical sense the ideal diets at different ages, but attempt to outline the influence of nutrition on growth and development.

Since there is no adequate definition for "optimal growth" there can be no "optimal diet." Individual variations must be taken into consideration, for the total energy output of any two subjects is never constant from day to day or from year to year. They may show considerably different utilization of their food, composition of feces, urine or blood and changes in body weight. Because of the many variables, no single dietary regimen can be used arbitrarily. Finally, much of our knowledge has been derived from animal experiments which cannot always be directly applied to man. With these facts in mind we hope in the following pages to show the important relationship between growth and nutrition at different ages.

TOTAL CALORIC REQUIREMENT

To provide the child with energy for maintenance, allowance must be made for (1) basal metabolism, (2) specific dynamic action of foods (S.D.A.), (3) caloric loss in excreta, (4) muscular activity and (5) additional energy for growth. Information regarding caloric requirements has been obtained largely through observations in the calorimeter (see Chapter 10).

During the first year to 18 months the daily requirement for basal metabolism averages about 55 calories per kg. (25 calories per lb.). After

this period the basal requirements tend to become gradually less (when based on weight), approaching the adult level of 25–30 calories per kg.[10] The premature infant's basal requirements are slightly lower than those for the normal newborn.

The specific dynamic action of food requires from 5 to 7 calories per

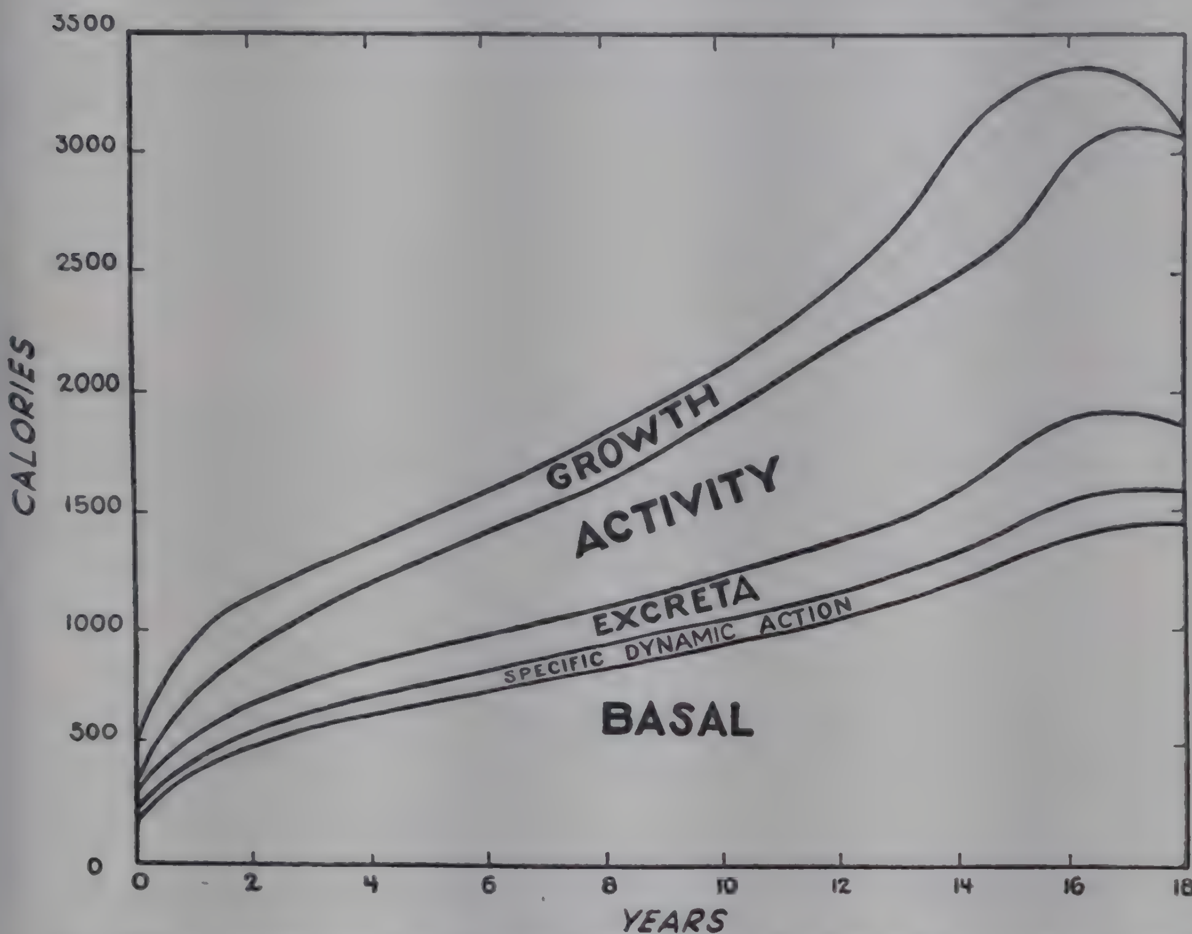

FIG. 56.—Average total daily caloric requirements for boys of average size, illustrating the number of calories allowed for each factor. (From Holt, L. E., Jr., and McIntosh, R. (ed.): *Diseases of Infancy and Childhood* [11th ed.; New York: Appleton-Century-Crofts Company, Inc., 1941].)

kg. on the average diet. When the diet contains a large proportion of protein the requirement may be more than doubled.

Approximately 10 per cent of the daily intake is lost in the excreta of the bottle-fed baby and older child and about 8 per cent of the breast-fed child. Most of it is lost in the feces.

The requirements for activity may vary tremendously per individual, at different age levels and for the two sexes. An average allowance during the first year is 20 calories per kg. (9 calories per lb.) per day. For the premature or phlegmatic infant this amount may be about half, whereas for an extremely active infant the requirements may be more than doubled.

During adolescence the requirement may also be proportionately high, especially for active boys.

Daily growth requirements are variable since growth is a dynamic process and, for practical purposes, represents calories stored.* During the early months of life 20–40 calories per kg. (10–18 calories per lb.) may be

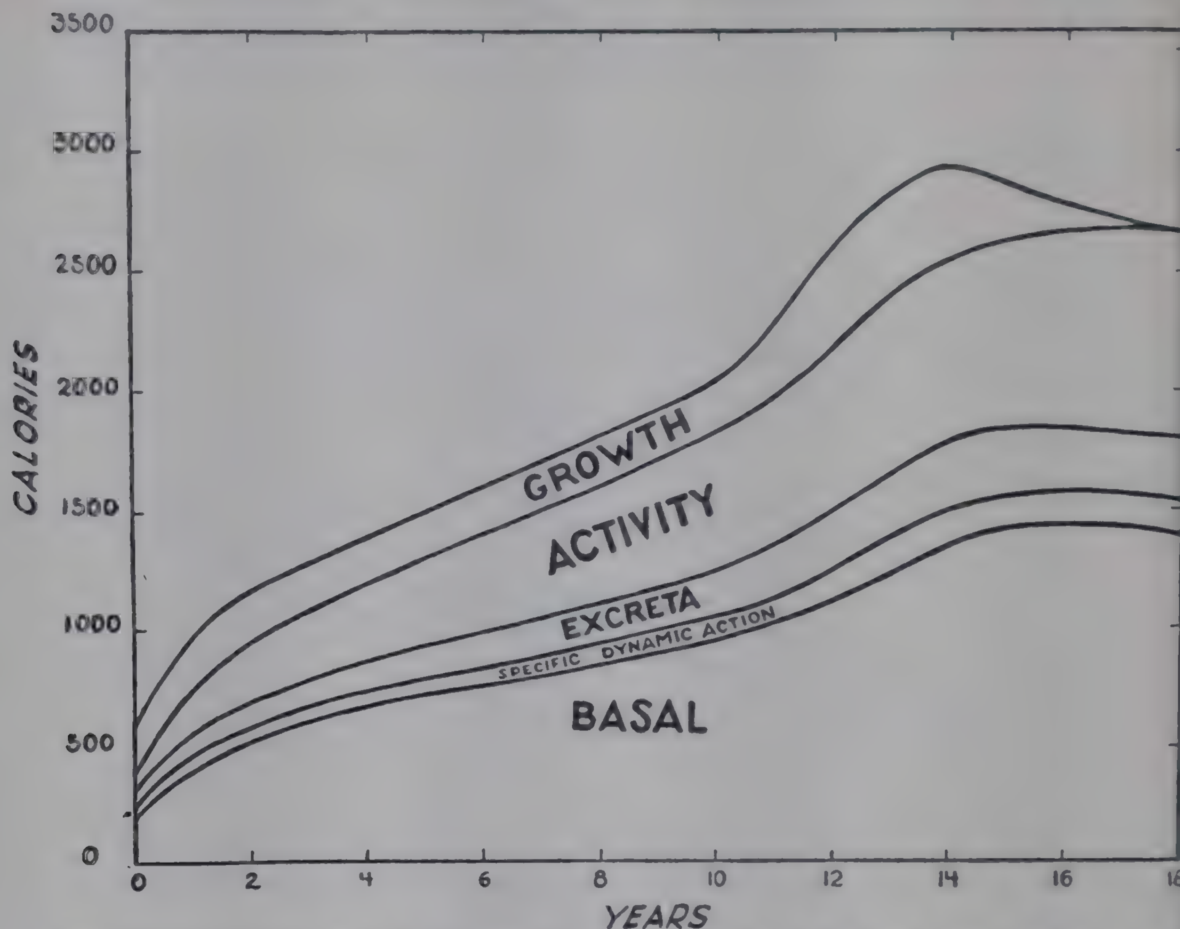

FIG. 57.—Average total daily caloric requirements for girls of average size, illustrating the number of calories allowed for each factor. Note that the peak of caloric requirement is reached about two years sooner in girls than in boys and occurs at about the time of menarche. (From Holt, L. E., Jr., and McIntosh, R. (ed.): *Diseases of Infancy and Childhood* [11th ed.; New York: Appleton-Century-Crofts Company, Inc., 1941].)

stored. By the end of the first year this allowance has fallen to 5–15 calories per kg. There follows a gradual decline in relation to body weight, with a temporary increase occurring during the spurt of growth which takes place before puberty.[10, 11]

In the premature infant the requirements for growth may double those of the normal newborn. It should be remembered that the "rate of

*From studies of protein metabolism, using nitrogen isotopes as tracers, there is evidence that growth results through a decrease in catabolism rather than an increase in anabolism.

growth" as shown in Wetzel's graphs (Fig. 52, p. 223) does not decline until the normal nine months of uterine life are completed. The increased allowance for growth must be maintained until the premature shows a "normal" weight for age relationship.

Figures 56 and 57 show the distribution of total caloric requirements for boys and girls at different ages, and Table 41, the average allowance

TABLE 41.—Total Caloric Requirement per Day (Cal./Kg.)

Age	8 Wk.	10 Mo.	4 Yr.	Adult
Basal	55	55	40	25
S.D.A.	7	7	6	6
Excreta	11	10	8	6
Activity	17	20	25±	10±
Growth	20	12	8–10	0
	110	104	87–89±	47±

as based on weight (cf. Fig. 51, p. 219). In obese and undernourished children one should calculate the total caloric allowance on the expected rather than on the actual weight of the subject, taking care to avoid "nutritional breaks" by any sudden or drastic changes in the diet.

PROTEIN

Proteins are normal constituents of all animal cells and body fluids except bile and urine. They are important in the regulation of osmotic relations of the intracellular and extracellular fluids and play an important role in the fluid balance of the body. Many of the body's enzymes have the properties of proteins and a considerable number of the hormones are proteins or protein derivatives. Many of the substances associated with immunologic and antigenic phenomena are proteins. In addition to these many functions found in the adult, this foodstuff serves the special function in the child of providing basic building materials for the manufacture of tissues during growth.[17]

Protein needs for growth are both qualitative and quantitative. Our knowledge concerning these needs comes from dietary surveys, measurements of nitrogen balance and creatinine excretion and estimations of the rate and composition of growth at different ages. An adequate protein intake may be defined as one which contains all of the essential amino acids in sufficient amounts to satisfy maintenance needs and to provide the surplus compatible with normal growth. The absolute amounts and percentages of the amino acids conducive to optimal human growth are not known. From the practical standpoint of feeding infants and children,

the protein foodstuffs of animal origin in common use (milk, meat, fish and eggs) supply all of the essential amino acids, and some foods of vegetable origin supply most of them in fairly high concentrations. However, Holt and Fales[9] have recommended that two thirds of the protein intake of children be given in the form of animal protein.

Studies of all age groups from prematures to adults show that in "normal" amounts proteins are readily digested and assimilated.

For the normal newborn infant a positive nitrogen balance results from an intake of 3–4 Gm. of protein per kg. per day. The requirement of

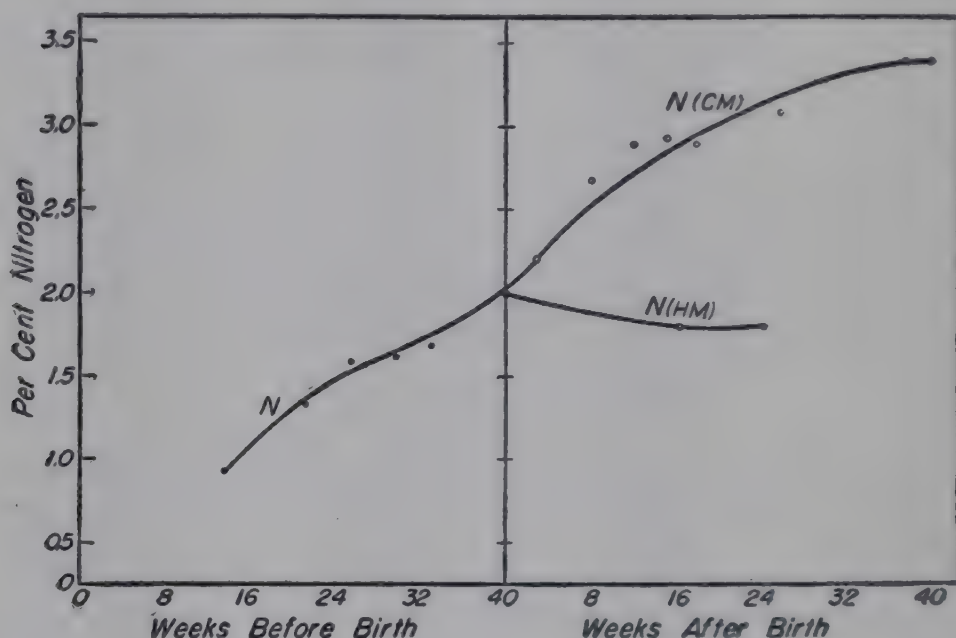

FIG. 58.—Nitrogen content of the body before and after birth. *N(CM)*, nitrogen content of infants fed cow's milk; *N(HM)*, nitrogen content of infants fed human milk. (From Stearns, G.: Physiol. Rev. 19:415, 1939.)

the breast-fed baby may be less owing to the high "biologic value" of lactalbumin[10, 19] (Fig. 58).

Levine[15] has shown that for the premature infant a relatively high protein intake, in contrast with human milk, results in a more constant weight gain, the nitrogen balances are of higher magnitude and the coefficient of digestibility of the more liberal protein intake is not reduced (85–90 per cent at all levels of dietary protein). To maintain an adequate nitrogen balance from human milk, there must be an excessive fluid intake (2.7 oz. per lb.) and the level of dietary fat frequently exceeds the fat tolerance of these immature infants when the caloric requirements are satisfied. Therefore, Levine used powdered cow's milk with a 1.5 per cent

fat content to feed premature infants. In addition, he believes the high mineral content of this food may be of definite benefit in preventing rickets. Levine has also demonstrated that vitamin C in large doses is essential for complete utilization of some amino acids by the premature infant.[16]

From the end of the first year through age 6 or 7 the protein requirement is fulfilled by an allowance of 3–4 Gm. per kg. per day.[19] There follows a gradual decline until, at 20 years of age, 1.5 Gm. is recommended. However, it has been demonstrated that children on very high caloric diets require relatively less protein to maintain a positive nitrogen balance and growth. Therefore, if large quantities of fat or/and carbohydrate are ingested there is a sparing effect on protein requirements.[24]

TABLE 42.—Average Caloric, Protein and Water Requirements

Age, Yr.	Cal./Kg.	Protein, Gm./Kg.	Water, Cc./Kg.
Premature	120	5.0–6.0	150
Infancy	110	4.0	150
1–3	100	3.5	125
4–6	90	3.0	100
7–9	80	2.5	75
10–12	70	2.0	75
13–15	60	1.5	50
15+	50	1.0+	50
Adult	40	1.0	50

Ingestion of very large portions of protein over a long period may have detrimental results, with diminished growth and diminished nitrogen retention.

In a small series of girls Johnston[12, 13] has shown that at the time of menarche and following this there may be a relatively brief but marked drop in nitrogen retention which may easily reach the point of negative balance if the dietary intake is not adequate.

Table 42 shows the average caloric, protein and water requirements at different ages.

CARBOHYDRATE

Carbohydrates supply the greatest percentage of calories and bulk of the average diet but constitute less than 1 per cent of the total body weight. The relatively small amount stored in the liver and muscles as glycogen is rapidly depleted in periods of starvation. Carbohydrate combined with protein in nucleotides and nucleoproteins may be found in every living cell. It is found combined with fat as cerebrosides and also is present in all connective tissue.

The main function of carbohydrate is to supply readily available energy for heat and muscular work. It spares protein and also exerts an antiketogenic effect by sparing rapid utilization of fat. Carbohydrate not oxidized or stored as glycogen is converted into fat and stored in the various fat depots.

Judging from the respiratory quotients and the blood levels of both term newborn and premature infants, carbohydrate stores are rapidly exhausted in the first few hours of life. However, the infant gastrointestinal tract easily digests and assimilates the disaccharides (milk and cane sugar) and monosaccharides (dextrose) from the time of birth, and once normal feedings have started the relative hypoglycemia (40–80 mg. per cent) of the first few days of life disappears and the respiratory quotient also rises.[22]

The relative requirements of children for carbohydrates do not differ from those of adults and are aimed at supplying a readily available source of energy. In general, it may be stated that not more than about 40 per cent of the total calories in an infant's formula should be in the form of carbohydrates. Later in life the optimal range is believed to be between 40 and 60 per cent of the total caloric intake.[10]

LIPIDS

The amount of fat present in the body varies with each individual. It is derived from ingested fat and from conversion of carbohydrate and protein in the body. In addition to its most commonly emphasized role as a source of concentrated energy, fat provides structural components for the repair and building of many body tissues, serves as a vehicle for the absorption of the fat-soluble vitamins (A, D, E and K), spares protein and is essential in the synthesis of the steroid hormones. There is some evidence that the highly unsaturated fatty acids are essential to life, and these cannot be synthesized by the body.

Few experiments have been carried out on children using low fat diets, but those few have indicated that fat is essential to normal growth and development. In the rat and dog, diets deficient in linoleic and arachidonic acids caused retarded growth and eczematoid skin lesions. Hansen *et al.*[8] believe that some infantile eczema is benefited by the addition of the fatty acids to the diet.

In the newborn infant fat retention is lower than in the year old infant. In the premature infant retention may be as low as 53 per cent

of the ingested cow's milk fat. Soybean oil and olive oil are apparently better absorbed by the premature and newborn infant than other fats. This low retention is due not to a failure of digestive enzymes but rather to lack of absorption from the alimentary tract. The inability to retain fat in large amounts is not overcome for several months after birth. For this reason, Levine and others have advocated formulas for the premature and newborn infant which have a relatively low total fat content.[7, 15]

Once the newborn infant has depleted his available glycogen stores (usually within the first day) he begins to depend on reserves of fat for energy, as demonstrated by a reduction in the respiratory quotient. During this process there is an increased transport of fat substances in the blood and nearly a twofold increase in the blood lipids between birth and the second week of life, although the total is still lower than in the child or adult.[22]

Although the breast-fed infant obtains nearly 50 per cent of his caloric intake from fat, it is the general consensus that after breast feeding is stopped, not over 35 per cent of the total caloric intake should be in the form of fat either for the infant or for the older child. Diets having very low fat contents lead to excessive carbohydrate intake, hunger and early fatigue.[10, 19]

Summarizing our knowledge of the role of proteins, carbohydrates and lipids in nutrition, we may state that all three are essential to optimal growth. The allowance for protein should be higher for the artificially fed infant than for the breast-fed infant. The infant fed cow's milk has a relatively greater retention of nitrogen and greater muscle mass than the infant fed human milk, but there is no evidence that this is of any great benefit. There is some evidence that properly prepared cow's milk is better suited to the premature infant than is human milk. Carbohydrate is well utilized as food at all ages and is the main source of energy. Lipids are the least well tolerated of any of the three basic foods, the younger the child the less being the tolerance.

MINERALS

The minerals are essential to normal body structure and function. The child requires at least 12 minerals in proper amounts for formation of new tissues and body fluids. At birth the mineral content of the body is 3 per cent of the total weight. Throughout childhood there is a steady

increase, both absolute and relative, so that in the adult 4.35 per cent of the body weight is mineral ash.

The minerals may be divided into three main groups. The important electropositive ions are sodium, potassium, calcium and magnesium. The electronegative ions are chlorine, phosphorus and sulfur. Iron and iodine and the trace elements represent a separate group physiologically.

Sodium is found chiefly in the extracellular fluids of the body, with a small amount in muscle, cartilage and bone cells. With chloride, bicarbonate, protein and phosphate it regulates the osmotic pressure and ionic equilibrium of body fluids. With calcium, potassium and magnesium it aids in control of the irritability of the neuromuscular system. The sodium content of the body is regulated by the adrenal cortical hormone and the acid-base balance and by hydration.

The sodium requirement for a child is normally met by the usual seasoning of foods with salt and the content of the foods themselves. Between 1 and 2 Gm. daily is sufficient unless there is excessive sweating.[18]

Potassium is the most important electropositive intracellular ion. Its functions are almost identical with those of sodium except that the latter is largely extracellular. In addition, it influences the irritability and conductivity of the heart muscle. Potassium metabolism is influenced by the adrenal cortical hormone, possibly by the parathyroid hormone and by ionic equilibrium of calcium, sodium and protein.

Since most foods contain an abundant supply of this mineral, a diet low in potassium is difficult to prepare. Between 1 and 2 Gm. is required daily.

Calcium occurs in the body to a far greater extent than any other positive mineral element. Ninety-nine per cent of it is found in combination with phosphates and carbonates as bone. Most of the remainder is found in the plasma, half of this being bound with protein and the other half in ionizable form.

Calcium furnishes important material for structure and growth of bones and teeth, and it supplies ions which function in muscle contraction, in the control of irritability of nerve cells and in the coagulation of blood and milk. It plays a minor role in electrolyte balance.

Calcium is easily absorbed as a soluble salt from the upper alimentary tract. The degree of absorption is influenced by the amount in the diet, the calcium:phosphorus ratio, the acidity or alkalinity of the intestinal tract and the presence of vitamin D. The calcium plasma level, which is

quite constant at all ages, is influenced by the parathyroid glands and the acid-base balance. Metabolism, mainly concerned with deposition in bone, is under the control of hormones from the parathyroids, pituitary, adrenal cortex and the sex glands as well as vitamin D.[21]

The amount of calcium retained by the growing child is about 25 per cent of that ingested, under ordinary conditions. During the first year, with an adequate vitamin D intake there is a greater storage in the body, both relative and absolute, when cow's milk is the source of food than when the source is human milk; however, there is no indication

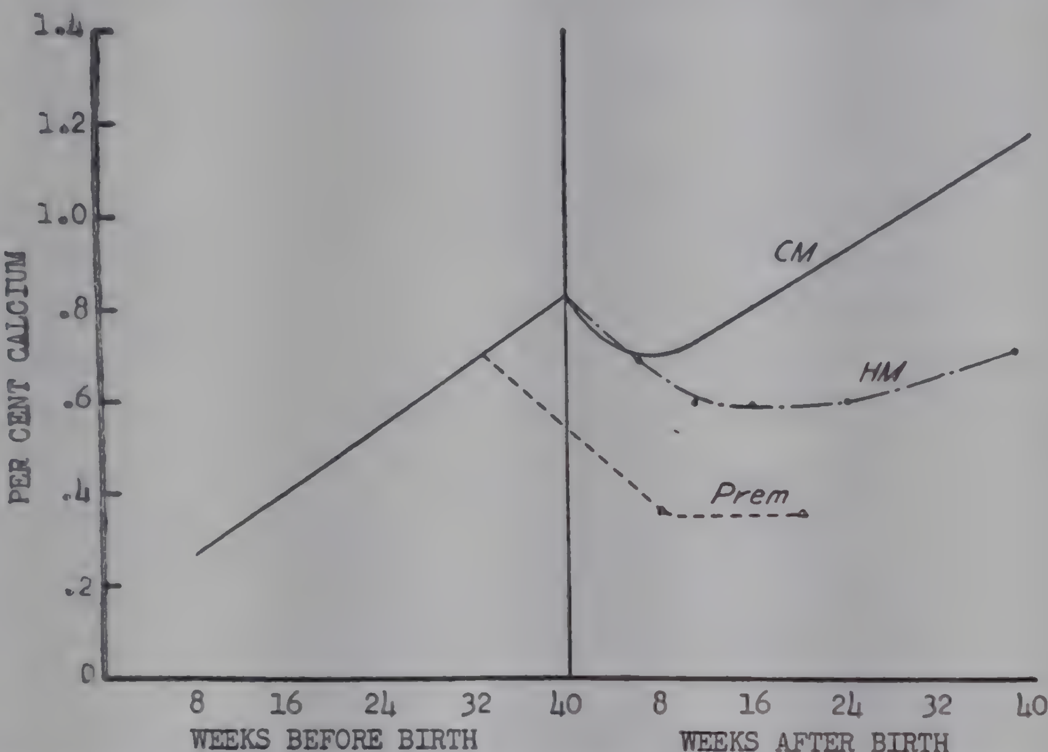

Fig. 59.—Calcium content of the body before and after birth. *CM,* calcium content of infants fed cow's milk; *HM,* calcium content of infants fed human milk; *Prem,* calcium content of prematures fed human milk. (From Stearns, G.: Physiol. Rev. 19:415, 1939.)

that this "supermineralization" is beneficial to the growing child. Levine believes this fact may be of some value in preventing rickets in the premature infant. It should be remembered that when the vitamin D supplement is inadequate, calcium and phosphorus absorption and retention are greater from human milk than from cow's milk. Therefore, in such instances rickets will be less common in the breast fed infant.[21–23] (Fig. 59).

Linear growth of babies fed a cow's milk formula is related to the amount of calcium retained. The differing retentions on a standard formula are obtained by variations in the vitamin D intake. The breast-

fed baby grows at a greater rate than the artificially fed baby when the calcium retention is the same.[11]

The quantity of calcium required by the growing child is estimated at between 50 and 70 mg. per kg. per day. In general, 1 Gm. per day with a calcium:phosphorus ratio of 1:1.5 appears satisfactory.

Magnesium is found in all body cells, but about 75 per cent is in the skeleton and a fairly large quantity is in muscle. Knowledge regarding the function of magnesium is meager. It serves as a catalyst in phosphorus and pyruvic acid metabolism and has a role in maintaining the electrolyte balance. It also is concerned with the regulation of nerve impulses and muscle irritability. According to Macy,[18] about 16 per cent of the intake is retained. The exact requirement is not known, but it is certain that the average diet contains an adequate amount.

Phosphorus is distributed in the body as organic compounds and inorganic phosphate. About 70 per cent of the phosphate is found in the skeleton combined with calcium. With potassium, phosphorus forms the most important intracellular mineral constituent of the body. In the organic form it is found in combination with fat, protein and carbohydrate.

Phosphorus is an important component of bone, muscle and nerve tissue. It plays a role in the absorption of carbohydrates and their transformation in muscular activity, in the transportation of fatty acids and as a buffer in the acid-base equilibrium. As cephalin it is essential to the formation of thrombin.

After birth the storage of phosphorus depends on the amount available in the diet, the stimulus to absorption and deposition offered by added vitamin D and the depression of absorption by large amounts of calcium or fats in the diet.[21]

In the newborn infant there is a very slight depression of serum calcium and elevation of phosphorus content as compared with the older infant. This has led the Bakwins[1] to postulate a relative hypoparathyroidism. Other studies of the newborn have shown that for several weeks after birth there is a gradual rise of plasma phosphatase from a very low level to a normal level of 10–14 Bodansky units at 4–6 months. Why phosphatase activity should be low at birth when calcification ought to be proceeding rapidly is not easily explained.[22]

With adequate vitamin D intake, growing children should have a phosphorus intake of about 1.5 Gm. daily. Except in children with rickets,

there is no known harmful effect from an excessive intake of phosphorus. Tetany may be precipitated in the presence of active rickets when large quantities of phosphorus are ingested.

Chlorine, as the chloride, is a component of all body secretions and excretions. With sodium it constitutes the most important electrolyte in the extracellular fluid, maintaining acid-base and water balances. Chloride excretion is influenced by the antidiuretic factor of the posterior pituitary gland and by the adrenal cortical hormone; however, these influences are probably secondary to water metabolism.

In normal conditions the intake of chloride does not require special consideration because it is abundantly supplied in many foods.

Sulfur is a constituent of all body protein in the form of amino acids. It is also found in combination with lipids and as inorganic sulfur. It occurs in melanin, vitreous humor, heparin, cartilage, nerve tissue, insulin, thiamine and enzymes of cellular respiration.

In general, the metabolism of sulfur is linked with protein metabolism since the greater part of the sulfur ingested is in the form of amino acids. Sulfur, as amino acid sulfur, is essential to growth. An adequate protein intake assures a sufficient allowance of sulfur; the ideal intake has not been established.

Iron is found in the body in relatively small amounts—approximately 3 Gm. in the normal adult. Fifty-eight per cent is in hemoglobin, 7 per cent in muscle hemoglobin, 15 per cent as chromatin in the cells and in cytochrome and the remaining 20 per cent stored in the liver, spleen, bone marrow and to less extent in other tissues. It is evident that the chief function of iron is to carry oxygen to the tissues and to aid in oxidation processes carried on by the cells.

Retention of iron, when ingested either as organic compounds or in inorganic forms, is largely regulated by the body's needs rather than by excretion. The ability to store iron is great, and it is used over and over again; i.e., the body has an endogenous source in the iron released during hemoglobin destruction.[21]

During periods of rapid growth the need for iron is greater than at other periods of life in order to avoid hypochromic microcytic anemia. The anemia of prematurity, occurring about two to four months after birth, cannot be prevented by giving iron prophylactically, but the severity and duration may be influenced to some extent by early administration of iron. The cause of this anemia is believed to be twofold: (1) the greater

portion of storage of iron by the fetus occurs during the last trimester (Fig. 60), and (2) more important, the premature infant grows relatively rapidly during a short span of time.[5]

The iron accumulated by the fetus is sufficient only for the first few months after birth, and the supply may be still less adequate in the case

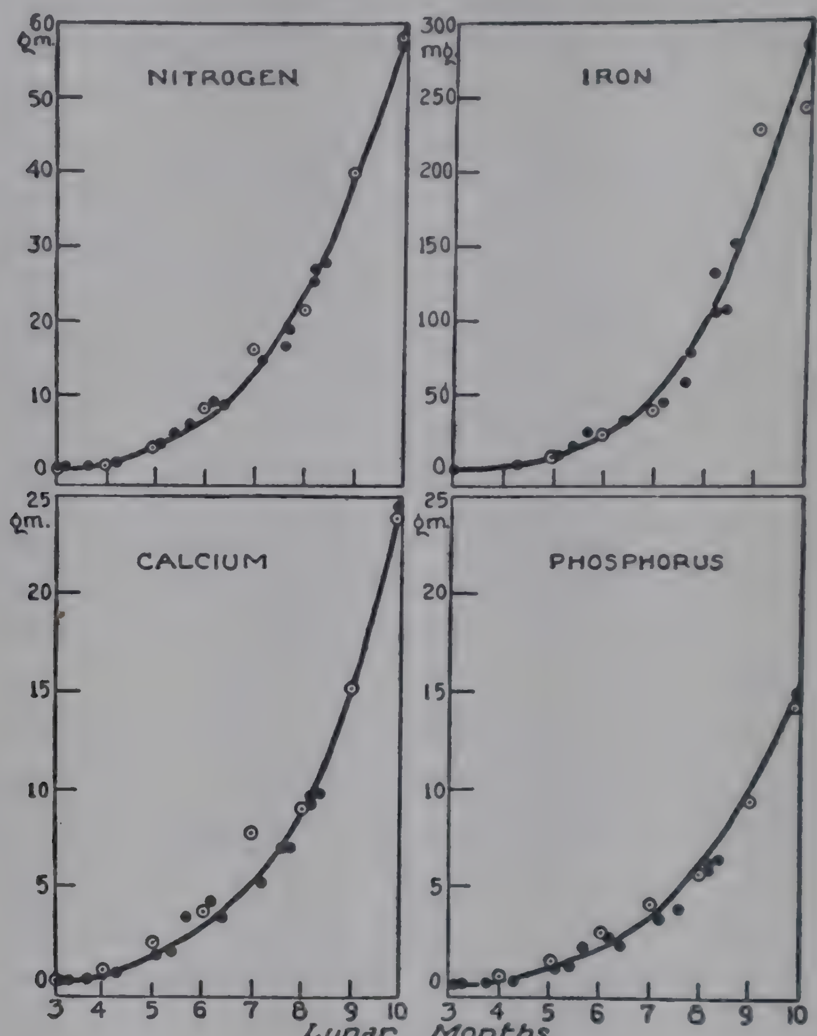

FIG. 60.—Nitrogen, iron, calcium and phosphorus content of the human fetus. It is apparent that the fetus retains the greatest proportion of all four of these substances during the final trimester. (From Swanson, W. W., and Iob, V.: Am. J. Obst. & Gynec. 38:383, 1939.)

of a maternal iron-deficient diet, multiple births or prematurity. Neither human nor cow's milk contains enough iron to meet the infant's needs. Cereals, liver and meat all supply iron, and for this reason they should be introduced into the infant's diet not later than the fourth month. The daily requirements for the growing child vary between 0.5 and 1.0 mg. per kg. per day during early life and 0.2 and 0.4 mg. for the older child.[18]

Iodine is necessary for the formation of the thyroid hormone and thus plays a vital part in body metabolism. It is readily absorbed from the alimentary tract in either organic or inorganic form. After absorption it is rapidly taken up by the thyroid gland. The amount retained by the body depends on the intake and the amount already stored.[21]

The work of Marine has well established the routine use of iodine prophylactically in a "goiter belt" area to prevent simple goiter. Iodized table salt usually supplies adequate iodine in the so-called goiter areas. For infants and children the daily requirements are stated to be 40 to 100 micrograms and for adolescents 100–200 micrograms.

The following minerals, found in very small amounts in the human body, are essential to normal growth and development.[20, 21, 23] *Fluorine* is apparently necessary for good tooth enamel formation. It is also found in bone, but its function here is poorly understood. *Copper* is found in larger quantities in the liver of the fetus than in the child after birth, and it is found in larger quantities in the bone marrow after birth than in the liver or bone marrow of the fetus. Since the liver of the fetus and the bone marrow of the infant are the chief sources of red blood cells, these variations lend support to the theory that copper is necessary for hemoglobin synthesis. It is also found in the enzymes tyrosinase and ascorbic oxidase. Since the normal diet contains traces of copper, its deficiency is not to be anticipated in the normal child. *Zinc* is necessary for growth in experimental animals; studies of zinc deficiency have not been made in human beings. It is found in the pancreas and in the enzymes carbonic anhydrase and uricase. *Manganese* has been found to be essential to normal development of the embryo of the rat and the chick. In young animals a manganese-free diet retards bone growth. Although the role of this element in human physiology is not known, the experimental observations and the fact that all tissues of the body contain traces of manganese would seem to indicate that it is an essential mineral. It is present in the enzyme arginase. *Cobalt* may be essential in traces as a stimulant to erythrocyte formation and possibly shares with manganese a catalytic action for various body enzymes.

VITAMINS

The vitamins are so well known that they will be considered very briefly and in outline form (Table 43). It is certain that they are essential to normal growth and development. A well rounded diet usually supplies adequate amounts of them, but during infancy and nutritional disturb-

TABLE 43.—VITAMINS ESSENTIAL TO NORMAL GROWTH*

VITAMIN	FUNCTION	CLINICAL DEFICIENCY	REQUIREMENT/DAY 1. INFANT 2. AGE 5 YR. 3. AGE 10 YR.	SOURCES OTHER THAN MEDICINAL
A	*a)* Forms visual purple (rhodopsin, iodopsin) *b)* Normal metabolism of epithelium	*a)* Nyctalopia, hemeralopia *b)* Xerosis, xerophthalmia, keratinization of epithelium of skin, alimentary, respiratory tracts	1. 2,000 I.U. 2. 3,000 I.U. 3. 4,000 I.U.	Milk, egg yolk, beef, liver, various fish oils
D	Ca and P metabolism (probably absorption & deposition of both)	Rickets, osteomalacia	1. 2. 3. } 400-800 I.U.	Fish liver oil, activated steroids, sunlight
C	*a)* Amino acid metabolism during growth *b)* Intracellular ground substance & intracellular cement *c)* Tissue respiration	*a)* Poor use of some aromatic amino acids *b)* Scurvy *c)* Tissue healing retarded	1. 30 mg. 2. 50 mg. 3. 70 mg.	Oranges, tomatoes, most citrus fruits
K	Prothrombin formation in the liver	Hemorrhage	?	Green leafy vegetables, soybean, rice bran
Niacin	Forms coenzymes I & II in cellular oxidation	Pellagra	1. 4 mg. 2. 8 mg. 3. 12 mg.	Liver, meat, whole wheat, milk
Riboflavin	Essential to formation of cellular respiratory enzymes	Corneal vascularization, glossitis, cheilitis	1. 0.6 mg. 2. 1.2 mg. 3. 1.8 mg.	Milk, liver, pork, eggs, vegetables, fruit
Thiamine	Forms cocarboxylase (pyruvic acid metabolism)	Beriberi, polyneuritis	1. 0.4 mg. 2. 0.8 mg. 3. 1.2 mg.	Milk, pork, egg yolk, cereals, vegetables, fruit

*From Butler,[3] Butt,[4] Elvehjem,[6] Gordon *et al.*[7] and Kugelmass.[14]

ances some of them should be given to supplement the diet. Neither human nor cow's milk supplies sufficient amounts of vitamins C and D, so they should be added to the infant's intake.

The vitamins to be considered here are the fat-soluble vitamins A, D and K and the water-soluble vitamins C, niacin, riboflavin and thiamine. Other factors in the vitamin B complex (pyridoxine, pantothenic acid, biotin, choline, inositol, para-aminobenzoic acid and folic acid) are probably essential, but their function in man is not so well understood and therefore are not discussed. Nor will vitamins E and P be considered.

Vitamins A, D and K are fat-soluble; therefore the ability to absorb fat must be present before they can be adequately absorbed. Vitamins A and D may be stored in the liver, so that large quantities given at one time are effective for relatively long periods. Vitamin D is also available in water-soluble form (activated ergosterols).[3, 4, 6, 10]

The body has very poor ability to store any of the water-soluble vitamins, consequently these vitamins must be ingested frequently in adequate amounts. In general, the factors of the B complex occur together in Nature so that a deficiency of any one is usually associated with a deficiency of the others.[6, 10]

The figures usually given for the requirements of the vitamins have been more or less arbitrarily chosen. Factors such as illness, malnutrition and increased activity are not considered. Finally, it has recently been demonstrated that some foods have a sparing action on vitamins of the B complex whereas others have an opposite effect. The amounts suggested in Table 43 are generally considered to give a wide margin of safety.

In the foregoing paragraphs we have indicated in a general way what substances are thought necessary and the quantities required, when known, for optimal growth and development. Alone, however, the figures are insufficient, for we must have some means of determining whether a child is or is not receiving the best nutrition possible. Actually, no such method is available. Average stature and weight are not necessarily proof that the state of nutrition is satisfactory. Investigations on vitamins, for instance, have shown that somatic growth alone is not an adequate index of certain important deficiencies in nutrition.[3, 26]

During both World Wars I and II it was demonstrated that with increasing food shortage there was an observable lowering of the average size of children. Maturation also was often delayed, as shown by the absence of menarche or its onset at a much later date than usual. The

effect of poor diet on pregnancy has been discussed in Chapter 3. When returned to an adequate diet after a period of undernutrition, children show a transient period of accelerated growth. During starvation certain organs continue to grow at a normal or near normal rate, i.e., the brain and heart, while other organs decrease in size, particularly the thymus and liver. The last-named organs undergo the greatest relative increment during the poststarvation acceleration. If starvation is not prolonged, no apparent permanent damage will occur in the final pattern of growth and development.

Some mention has been made of the effect of nutrition on immunity and resistance to disease (pp. 213 and 233). It is well known that an inadequate protein intake will lead to inferior production of antibodies, presumably because of poor globulin formation. Johnston[13] has repeatedly stressed the importance of an adequate diet, especially protein and calcium, during the adolescent period. He believes that a negative balance of these important food elements plays a major role in the reinfection or adult type of tuberculosis which is so common at this age. It is probable that other nutritional factors play a role in immunity, but they are not clearly understood.

FOOD HABITS

As the child grows he develops food habits. These change with increasing maturation of body and mind and are related to his nutritional requirements, his personal satisfactions and dissatisfactions and to the impact of the society around him. The psychologic reaction of the child to the offering of food is receiving much attention at present, and properly so.

The foundations of eating behavior rest on the physiologic mechanisms of hunger and appetite and their gratification. Hunger contractions almost certainly occur in the stomach of the newborn. This is an unpleasant sensation and is relieved by the ingestion of food. The infant, at this time and later on, does not tell when he is hungry by looking at the clock, as do most adults. It seems advisable, therefore, to have a feeding schedule flexible enough to coincide with hunger time. This establishes good feeding behavior at the outset and may avoid trouble later on. It might be well to add at this point that the amount offered should be sufficient to satisfy. Many cases of "colic" in infants are related to underfeeding and poor feeding technic.

The time to add solid food to the infant's diet comes when he is prepared for it and may vary over a wide range from one to perhaps four months. There is no valid indication that immaturity of the gastrointestinal tract precludes the introduction of solid food in the diet even before this, but little is to be gained and the chances of aspiration are certainly increased. The time at which chopped or more coarse food should be added depends on the child's rate of progress and, from a purely nutritional standpoint, makes little difference. An adequate diet may be secured in a variety of ways, and either forcing or overly delaying new food experiences is hardly to be desired. Most "chopped" or "junior" foods need little mastication so that dentition is not a particularly important consideration until even coarser foods are introduced.

As motor skills increase the child needs less and less help in eating. Some children are fairly proficient in feeding themselves by 18 months, but in many this skill comes later. The child should be allowed some choice in his diet by this time and his likes and dislikes should be respected. By age 5 years he can handle a knife and fork quite well, although he still needs occasional help. It is important throughout childhood that mealtime be a happy time in order to insure good habits.

It is common during the second or third year, sometimes sooner, for the parents to be overly concerned with the child's appetite. This is often a period of physiologic anorexia (see Fig. 52, p. 223). It must be realized that by this time the rapid growth which characterized infancy is over. The rate of weight gain reaches its lowest point during this time and the relative metabolic rate is also at a low level. In addition, this is a period in the child's life when he is becoming aware of himself as an individual and as a part of the family group. His interests are not as concerned with eating as they formerly were. He may like to exert his authority by seeing the effect of his not eating on his parents, especially if they appear worried about it. If these facts are explained to parents and they are assured that no healthy child (physically and mentally) will starve himself if food is available, many disagreeable behavior problems will be avoided. Often asking the child to participate in preparing the food or the table will renew interest. Smaller helpings may also be desirable and make the goal of "cleaning the plate" more easily attained.

As we have seen, the pattern of growth differs not only for each age but to a considerable extent in the individual. Knowledge of the progress of growth in a particular child may contribute to an understanding of

food needs and, in turn, to an understanding of appetite. The Wetzel grid, based not on age, but on the degree of development, has been used by many to determine the total caloric requirement. Regardless of the method used to determine dietary needs, to be of value it must respect the pattern of growth of the individual.

The effect of illness on appetite is well recognized. The fact that some anorexia may persist beyond the time of obvious signs and symptoms of illness must also be realized to avoid the introduction of poor food habits. Fatigue, excitement and temporary emotional disturbances occur in every normal child at one time or another and their interference with appetite should be respected. The small child has a short attention span and often has great difficulty in sitting still during a meal. All of these factors play a part in development related to food intake, and a reasonable attitude toward them is essential.

The environment in which the child eats may also influence him. Some of the more important factors pertain to the economics of the family, the cultural food pattern of the family, the availability of food and the attitude of the family toward food in general or toward particular preferences or prejudices.

It is apparent that nutrition in children is more than a simple matter of chemistry and physiology based on laboratory studies. The other factors, though only briefly considered, should be constantly kept in mind by the person who must guide parents and children and hopes to establish good habits in them.

DIETARY REQUIREMENTS

The complexity of the newer knowledge of the nutrition of children has only been touched on in this chapter. We have made no attempt to outline the actual preparation of formulas or diets, since this is done in most textbooks of pediatrics or in dietary manuals. Owing to common demand by those who reviewed this chapter during its preparation, we present some basic data in Table 44.

TABLE 44.—REQUIREMENTS OF SOME ESSENTIAL NUTRIMENTS

Estimation of total caloric requirements, daily

Infancy: 45-55 cal./lb. expected weight for age.

Childhood: 1,000 cal. basic plus 100 cal. for each year; e.g., a boy aged 9 should have 1,000 plus 900, or 1,900 cal. daily.

Estimation of protein requirements, daily

Infancy: 2 Gm./lb.; an adequate amount is assured if the infant consumes 1¾ oz. whole milk/lb. or slightly less than 1 oz. evaporated milk/lb. daily.

Childhood: 1 Gm./lb. until puberty, when slightly more is desirable.

If about 20% of the required caloric intake is protein, the requirement will be met.

Minerals, daily

Calcium, 1–1.5 Gm.

Phosphorus, 1.5 Gm.

Iron, 16 mg.

Iodine, 100–200 micrograms (trace)

Vitamins: see Table 43

Composition of daily diet to satisfy basic growth needs

Milk	¾–1 qt.
Meat, poultry, fish	1 serving (5–6 weekly)
Liver	1 serving weekly
Eggs	1 (5–6 weekly)
Vegetables, 1 raw, 1 pigmented	2 servings
Fruit, fresh, 1 citrus	2 or more servings
Butter	2 tsp.
Bread (enriched or whole grain) and cereals	enough to meet caloric needs
Salt (iodized)	Seasoning
Cod liver oil	1 tsp. or equivalent

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12

Facial Growth and Dentition

GROWTH OF THE CRANIOFACIAL SKELETON

Embryology of the Facial Region

With the definition of the branchial arches during the fourth week of intrauterine life the history of the human facial region begins. The primitive buccal cavity is bounded by the frontonasal process and the maxillary and mandibular processes of the first branchial arch. The frontonasal process elaborates, at its inferior margins, into paired median and lateral nasal folds which form the nares. Each maxillary process moves toward the midline and joins with the lateral nasal fold of the frontonasal process. As this is happening a shelflike process, the palatal process, is developed on the medial side of each maxillary process. The two palatal processes move toward the midline where they fuse. Anteriorly they join with similar intraoral projections from the nasal processes to form the primitive palate. The two mandibular processes meet at the midline somewhat earlier than the maxillary and nasal processes meet.

Failure of fusion of the palatal processes gives rise to cleft palate. If the nasal and palatal processes fail to unite, the lip and alveolus may be cleft as well. Cleft lip and/or alveolus may appear either bilaterally or unilaterally and is usually associated with cleft palate, though either may occur alone. Palatal fusion is usually completed by the eighth week.

Prenatal Bone Formation in the Craniofacial Complex

In the embryo, the entire cranial skeleton is first found as a framework of mere connective tissue. The cranial base is converted to cartilage. During the second month of intrauterine life, bone starts to form in the connective tissue of the cranial vault and face and in the cartilage of the

cranial base. These ossification centers spread out in the rapidly growing fetus and finally at birth are separated from each other by connective tissue or cartilage. In the cranial vault at birth, connective tissue partitions between bones are wide and at their widest areas form the six *fontanels,* distributed at the different corners of the parietal bones (see Fig. 16). The areas of cartilage between bone in the cranial base are termed

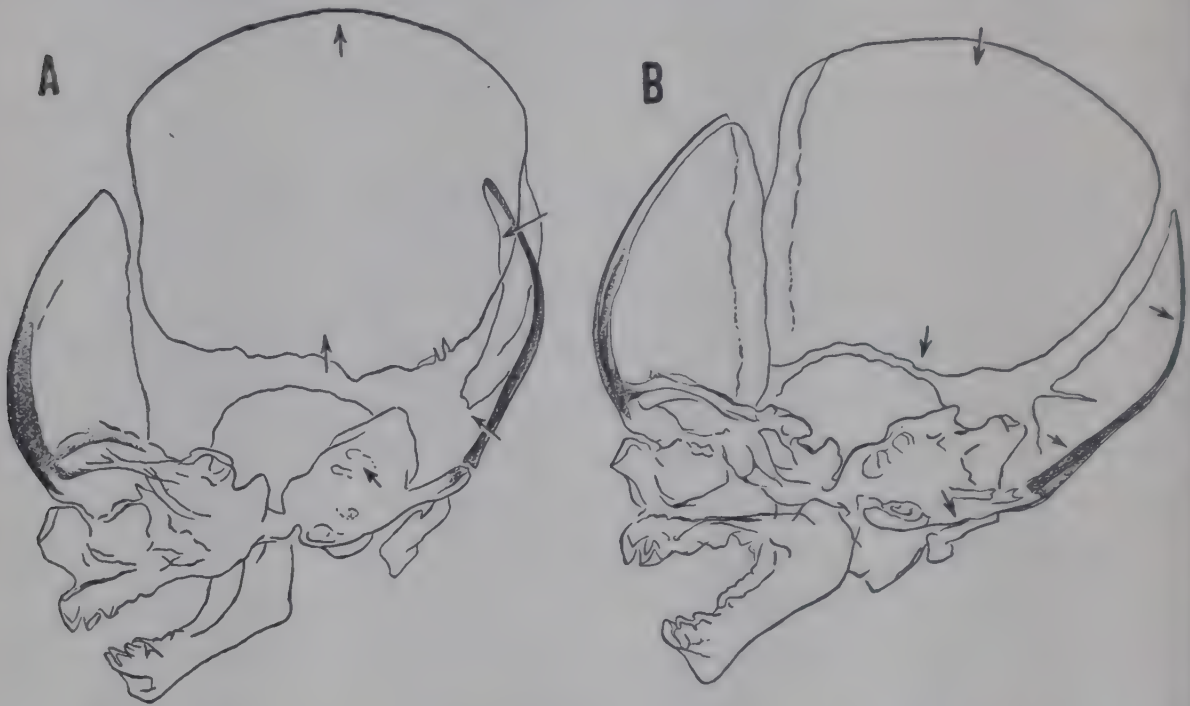


Fig. 61.—*A,* tracing of roentgenogram of neonatal skull on first day of life, demonstrating molding of bones of the calvarium with overlapping of their edges and narrowing of sutures caused by compression during passage of head through the birth canal. Parietals are displaced upward and temporals and occipital are rotated counterclockwise. *B,* tracing of roentgenogram on third day of life, showing re-expansion of cranium and widening of sutures and fontanels, as compared with *A,* after parietal, occipital and temporal bones have returned to normal positions. (Courtesy of Dr. H. C. Moloy; from Caffey, J.: *Pediatric X-ray Diagnosis* [2d ed.; Chicago: Year Book Publishers, Inc., 1950].)

synchondroses. At birth the skull contains 45 separate bones, which are reduced in the final adult skull to only 22 bones. For example, at birth the frontal bone is divided by the inter-frontal or metopic suture; the parietal bone is paired; the occipital bone is found in four separate parts, with synchondroses between each part, and the tympanic annulus is not fused with the temporal bone. Many of these sutural connective tissue and cartilaginous partitions disappear soon after birth; e.g., the metopic suture narrows soon before birth, begins to fuse at 2 years and is fused by 6.

Recovery from Birth Molding

In order for the head to pass through the birth canal the cranial bones must pass over one another, thus decreasing the skull's diameter. This is possible in the neonate because of the wide cranial sutures and the fontanel. Any study of the newborn's head must differentiate between recovery from bone molding and growth.

1. Cranial vault.—During birth molding "the two halves of the frontal bone are pushed posteriorly ..... Their movement is made possible by an actual bending and also perhaps by their approximation or even overriding at the midline." The parietals are pushed superiorly and overlay both the occipital and the frontal squama (Fig. 61). There is a wide margin between the parietals and the superior border of the temporal squama. During recovery of the brain, these displaced bones are carried back to their original positions, and a smooth contour is attained. This happens by the third day, and the individual patterns then become apparent. The calvariums of babies delivered by cesarean section do not show as much deformation as those of normally delivered babies.

2. Cranial base and face.—Normally neither the cranial base nor the face is distorted during the birth process. The premaxillary region may be seriously disturbed if the physician inserts his finger into the mouth in order to pull the head during delivery.

Growth of the Cranial Vault

The cranium at birth is eight to nine times the size of the face. The face of the adult is one-third to one-half the size of the cranium. Growth of the cranium is very rapid for the first year or two of life, then slows down considerably. It attains 90 per cent of its adult size by age 4–5, then slowly reaches adult proportions at 10–12 years of age. Its rate of growth exceeds that of the rest of the skull for the first six months or so of life, then the growth of the face overtakes it.

The cranium expands because of pressure of the growing brain. At birth the skull bones are so thin that they contain no diploe. Bone apposition in the cranial vault is responsible for the increase of its thickness, thus permitting the development of a diploic layer between a thick outer table and a thinner inner table; the vault becomes trilaminar at 6 years of age. Resorption and apposition in the cranial vault change the shape of the

individual bones and give the vault a more adult-like appearance. The varying rates of sutural deposition also contribute to the changing proportions of the growing skull.

Width.—The cranial vault grows in width by apposition on the outer surface. Excessive thickness is prevented by concomitant resorption in the inner table. Growth in the midsagittal suture between the parietal bones and in the sagittal suture between the frontal bones adds to increase in width as well. Sutures are used not only for active growth but also for adjustment or regulation of a bone when growth occurs at a more distant suture. Without this freedom or adjustment mechanism, the growth of individual bones would be impossible because they would become locked or imprisoned by the surrounding bones.

Height.—The cranium increases in height by sutural growth and to a lesser extent by appositional growth on the outer table of the cranial vault.

Length.—The infant's cranial vault increases in length by two mechanisms. (1) It is carried to a greater length because it is attached to the cranial base, which increases in length. (2) This increase in length is made possible since the sutural growth in the coronal suture keeps pace in its growth rate with the increase in length of the cranial base.

Growth of the Cranial Base

The cranial base is the most stable area in the skull during growth. Because the cranial vault and the nasomaxillary complex are attached to the cranial base, its growth is a determining or limiting factor in the growth of the rest of the skull. The cranial base increases in width by sutural growth in the sphenoid region and in height by apposition. Its length is increased by sutural apposition in the spheno-occipital and spheno-ethmoidal sutures. The spheno-occipital synchondrosis contributes to growth in an anteroposterior direction until some time after puberty. Different investigators suggest that this stops between the ages of 12 and 20. The sphenoethmoidal synchondrosis contributes to growth in length for a longer time and at a faster rate than the spheno-occipital suture.

Growth of the Nasomaxillary Complex

The nasomaxillary complex at birth is farther from its adult dimensions than is the cranium. Height and length are less developed than

width because they are largely dependent on alveolar growth which is yet to come. The body of the maxilla will also be increased in height and length by sutural growth. At birth the orbits have attained more of their adult size than any other portion of the face. The uppermost boundaries of the nasal cavities have also attained most of their adult size.

Width.—Confusion has arisen regarding maxillary width because of varying points of measurement. Three regions of the nasomaxillary complex are anatomically distinct and their width increments should be discussed separately.

a) Palatal width. The palate contains three paired bones: the palatal

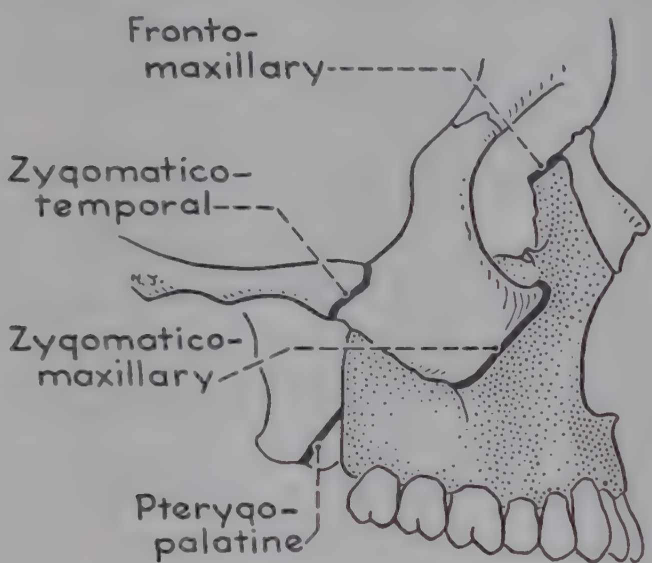


Fig. 62.—Paired parallel sutures of nasomaxillary complex. The resultant vector of growth at these sutures is downward and forward in a direction similar to the growth vector of the mandible.

process of the premaxilla, the palatal process of the maxilla, and the horizontal process of the palatine bone. During the first year of life the palate and maxilla increase in width and over-all dimensions by external surface apposition, just as they do prenatally. Then growth becomes selective or localized to specific areas. The premaxillo-maxillary suture closes in early infancy. After its closure the anterior portions of the palate and maxilla become no wider. In the fourth to fifth year the sagittal suture begins to fuse and palatal width is fixed. Alveolar width for the developing molars is achieved by external surface apposition on the alveolar bone buccally.

b) Bizygomatic width. Bizygomatic width increases, especially in the male, up to about age 17, which means that there is little correlation between palatal and bizygomatic widths. Bizygomatic width increases

smoothly and steadily at a constantly diminishing growth rate from infancy until adulthood.

c) Maxillary width. The maxilla increases in width by surface apposition on its lateral walls, keeping pace with palatal and bizygomatic widths. Alveolar bone changes provide for the discrepancies in labiolingual thickness between the deciduous and permanent teeth.

Height and length.—Increases in these two dimensions occur together since the vector of growth in the nasomaxillary complex is down and forward. The nasomaxillary complex is joined to the skull by four paired and parallel sutures (Fig. 62) which contribute to this downward and forward movement since they join the face with the relatively fixed cranial base. As the nasomaxillary complex moves down and forward, space is provided for growth of the maxillary tuberosity.

Growth of the Mandible

In the neonate the bone is ill-defined, the alveolar process is scarcely present, the rami are proportionately short and the condyles have not yet become well developed. At this time the mandible grows at all its surfaces and borders to increase its over-all size. Symphyseal growth occurs also, increasing the width of the mandible. However, by the second year the symphysis is closed and growth becomes localized in the mandible as it is in the nasomaxillary complex.

Two types of bone growth are observed in the mandible: endochondral, and appositional growth on the surfaces. Except for the condylar area, all increases in size are due to subperiosteal deposition of bone. This apposition of bone may take place in response to muscle function, condylar growth or the eruption of teeth.

The main growth center in the mandible is in the hyaline cartilage of the condyles and its fibrous connective tissue covering. The condylar growth center is unique in the body, since it grows both interstitially, by means of its cartilage, the deepest layers being converted to bone, and appositionally, by means of the connective tissue layer immediately covering the cartilage, the deepest layers being converted to cartilage.

Condylar growth increases the over-all length of the mandible as well as ramus height. Since the condyles rest in the glenoid fossae of the cranial base, backward and upward growth of the condyles positions the mandible downward and forward. Sites of apposition and resorption elsewhere in the mandible occur smoothly and in an even pattern only because growth

in the condylar centers moves the mandible away from the upper face, creating the room necessary for these other sites of development.

As the mandible moves down and forward away from the cranial base, the entire ramus is reshaped. Resorption takes place along the anterior border of the ramus and concomitant deposition occurs along the posterior border. This resorption seems to happen to provide room for the permanent molars, as the growth is most rapid just before the eruption of each of these teeth.

The role of the muscles in defining the shape of the mandible is best illustrated by the development of the coronoid process. Before birth it is ill-defined, but the muscle contractions of sucking, mastication, swallowing and speech draw the bone to its adult form. Thus the entire ramus goes through repeated remodeling to keep pace with condylar growth.

The body of the mandible grows largely posteriorly. This lengthens the mandible and causes the bigonial width to increase since the halves of the mandible diverge. There is scarcely any appositional growth on the inferior surface of the mandible, but there are small amounts of resorption and deposition on the lingual and buccal aspects of the body. There is a commonly held idea that a great amount of lateral growth of the mandible is observed. This is a misconception, for only very small increases in mandibular width, at a given point, are measurable.

During the first years of life when the tooth germs are developing at a rapid rate, the alveolar process begins to form. Only the alveolar process is dependent on the presence of teeth for its size, the rest of the bone develops to adult dimensions with less regard to the number of teeth. Individuals with anodontia have over-all mandibular dimensions similar to those of persons with a full complement of teeth, but the alveolus is nearly absent.

At birth the shortness of the rami and the lack of alveolar bone combine to give the appearance of an obtuse mandibular angle. Such is not the case, for it has been well established that this angle shows little change throughout life. In senility, the loss of the alveolar processes again gives the illusion of obtuseness.

The Pattern of Facial Growth

The entire face grows down and forward with a fairly constant relationship to the anterior cranial base. In fact the vector of downward and forward growth is normally along an axis joining sella turcica and

gnathion. Since the mandible is farther from its adult dimensions than the upper face, it must grow at a faster rate. This is particularly true immediately following birth.

The varying speeds with which each dimension in the face and cranium is accomplished are shown below. Note how much earlier cranial size is completed. One of the best reasons for careful supervision of facial

Percentage of Adult Facial and Cranial Dimensions Achieved at Different Age Levels*

Age, Yr.	Cranium of Adult Dimensions				Face of Adult Dimensions			Volume Ratio
	Width	Height	Length	Bizygomatic Width	Bigonial Width	Height	Length	Cranium Face
0				56		38	40	8 : 1
2	86	92	86	80		68	70	5 : 1
6	92	96	90	83	83	80	80	3 : 1
12	98	99	96	90	93	89	87	2.5 : 1
	max. attained by 15 yr. of age							
18	100	100	100	100	100	100	98	2 : 1

*From Moyers and Hemrend.[7]

and dental growth during early childhood may be found by noting the large proportion of the adult facial dimensions acquired before the age when the mixed dentition is finished.

THE DEVELOPMENT OF OCCLUSION

Development of Primary Occlusion

Interdentation of the primary teeth occurs before age 3 in most instances. There is less variability in occlusal relations in the primary than in the permanent dentition; however, some of the variations seen are of great clinical significance.

The mandibular denture occludes within the maxillary denture throughout its circumference. Most primary arches are ovoid, and there seems to be less variation in conformation than in permanent arches. Usually there is generalized spacing of all the anterior teeth (Fig. 63), although there are somewhat wider spaces mesial to the maxillary cuspids and distal to the mandibular cuspids—termed primate spaces since they are particularly prominent in the dentitions of certain lower primates.

Contrary to popular opinion the spacing between the primary teeth is not due to growth in width, for little increase in this dimension is seen. Spacing is either present or absent in primary dentitions; it does not increase with age.

It will be observed in Figure 63 that each mandibular tooth occludes one cusp anteriorly to the corresponding tooth in the maxilla. This is normal, and any deviations from this pattern are symptomatic of malocclusion. The most posterior surfaces of the second primary molars usually form a straight terminal plane. Interproximal cavities, sucking habits or a deformity of the facial skeleton may cause development of a terminal plane with a step. This plane largely determines the occlusal relationship of the first permanent molars which erupt just behind the second primary molars.

The primary occlusion is usually very stable, showing fewer anomalies than either the mixed or the permanent dentition. The most typical malocclusion is that caused by a severe sucking habit. Many children engage in sucking habits during the first 3 years of life with little damage; still, such habits give rise to many severe problems in the development of occlusion. An anterior open bite is typical. If the anteroposterior relationship remains normal and the habit ceases by age 4, the condition is self-correcting most of the time. If the mandibular teeth are occluding one cusp posteriorly, the problem seldom resolves itself and severe malocclusion may result in the permanent dentition. Many flippant remarks have appeared in the literature regarding sucking habits. Even though not all children with finger- and thumb-sucking habits seriously distort the occlusion, the treatment of all resulting malocclusions is a serious, time-consuming matter. A sound diagnostic procedure would seem to be to consult an orthodontist when in doubt. Those who belittle the possible effects of pressure sucking habits on the development of occlusion are seldom those who must treat the resultant problem.

Eruption of Permanent Teeth

Eruption is the process of movement that takes the tooth from its developmental crypt and places it within the oral cavity in occlusion with its antagonist. As the tooth moves out of the alveolus into the oral cavity many processes occur simultaneously. Alveolar bone deposits, the roots of the primary predecessor resorb and the roots of the permanent tooth elongate. Though these three processes usually are synchronized to occur simultaneously, they are not so dependent on one another as once was thought.

a) Factors regulating eruption. It has been shown repeatedly that eruption is under endocrinal control—perhaps a mechanism similar to that

regulating bone growth, for the teeth tend to erupt more rapidly during periods of accelerated osseous deposition. Certain systemic diseases may diminish all growth processes, including eruption. But the most important factors affecting eruption are those altering the expected time or order of development. Variations in time or sequence of eruption may be due to heredity, systemic disease or localized pathologic conditions.

b) Time of eruption. Much has been written about the expected time of eruption of each permanent tooth. Due to the great amount of variability the exact moment of arrival is of little importance. What is significant is the order and the site of eruption (see Table 46 for the mean times of eruption for the permanent teeth). Do not become alarmed if a given case is slightly behind or ahead of the times listed. Gross deviations, however, are matters of concern.

c) Sequence of eruption. Certain sequences of eruption provide optimal

TABLE 45.—Normal Sequence of Eruption of Permanent Teeth*

Mandible	Maxilla
1. First molar	2. First molar
3. Central incisor	5. Central incisor
4. Lateral incisor	6. Lateral incisor
7. Cuspid	8. First bicuspid
9. First bicuspid	10. Second bicuspid
11. Second bicuspid	12. Cuspid
13. Second molar	14. Second molar

*The numbers indicate the usual sequence of eruption.

opportunity for all the permanent teeth to erupt in their correct position. Other orders of eruption cause a rapid closing of space with resultant malocclusion. The desired, and normal, order of eruption is shown in Table 45. Ordinarily the mandibular teeth erupt ahead of the maxillary, except for the variation noted in the cuspid-bicuspid region.

Development of the Permanent Occlusion

1. Mixed dentition stage.—That period when both primary and permanent teeth are in the mouth is known as the mixed dentition. Those permanent teeth which follow into a place in the arch once held by a primary tooth are called successional or succedaneous teeth, e.g., incisors, cuspids, bicuspids. Those permanent teeth which erupt posteriorly to the primary teeth are termed accessional teeth.

With the arrival of the first permanent tooth begins the hazardous process of transition from the primary to the permanent dentition. During

this period, which normally lasts from 6 to 12 years of age, the dentition is highly susceptible to environmental changes.

2. *First molar eruption.*—In most children the first molars are the first permanent teeth to erupt. Before their eruption the primary arches should display a straight terminal plane (vertical tangent touching the distal surfaces of both second primary molars) or more favorably a mesial step (distal surface of the lower second primary molar mesial to the distal surface of the upper second primary molar).

3. *Incisor eruption.—a)* Mandibular incisors. The eruption of the first permanent molars is followed almost immediately by the eruption of the mandibular central incisors. They, in turn, are followed by the mandibular lateral incisors. Some have claimed that the incisors frequently erupt before the molars in the permanent dentition and that this predisposes to malocclusion. Lo and Moyers[5] found this sequence to occur so rarely that it has little significance. The mandibular incisors develop lingually to the resorbing roots of the primary incisors, the latter being moved labially as they are exfoliated. If the roots of the primary teeth are not properly resorbed, the permanent incisors may erupt into the oral cavity behind the primary incisors. Removal of the primary incisors allows the tongue to push the permanent incisors labially to their correct position. When the normal primary spacing is present, the permanent incisors erupt without showing crowding and attain good alinement. Lack of spacing in the primary anterior segment may be the result of a narrow alveolar arch. The permanent incisors, then, are more apt to be crowded on eruption.

b) Maxillary incisor eruption. The maxillary central incisors erupt just after the mandibular central incisors. They may also follow the lower lateral incisors. There is a marked change in incisal angulation with the eruption of the permanent central incisors, the almost vertical primary tooth being replaced by a permanent one with a decided labial inclination. The central incisors erupt with a slightly distal inclination and some space between them. This is diminished with the eruption of the lateral incisors and completely closed as the cuspids wedge their way into place.

The maxillary lateral incisors may experience more difficulty in assuming their normal position. As they erupt they are often seen slightly labially to the central incisors. As the cuspid erupts it releases its pressure against the root of the lateral incisor, permitting the latter to fall into line.

4. *Cuspid and bicuspid eruption.*—The favorable development of

occlusion in this region is largely dependent on two factors: proper tooth size–arch length ratio, and maintenance of a desirable sequence of eruption.

a) Mandible. The most favorable eruption sequence in the mandible is cuspid, first bicuspid, second bicuspid. All three should precede the second molar.

If the teeth are too large for the alveolar space, the second bicuspid may have insufficient room and be forced to erupt lingually. A similar malocclusion is seen when the primary molars have been destroyed by caries or they are exfoliated prematurely. The early loss or destruction of the primary molars permits the permanent molars to tip forward, decreasing the amount of space available for the cuspids and bicuspids.

b) Maxilla. The eruption sequence, it will be remembered, is different in the maxilla, i.e., first bicuspid, second bicuspid and cuspid. The maxillary anterior segment is not prone to collapse lingually since it is supported by the mandibular arch. It is, however, very easily displaced labially, e.g., by thumb-sucking or a tongue thrust.

When the maxillary primary molars are lost prematurely, the cuspid is blocked out of position labially. Extreme labial malpositioning of maxillary cuspids and lingual malpositioning of mandibular second bicuspids are often signs of the same problem—insufficient space. The malocclusion varies with the jaw because of the difference in eruption sequence. In each instance the last tooth to erupt in front of the first molar is the tooth forced out of position.

5. *Second molar eruption.*—The second molars should erupt after all teeth anterior to them are in position, the mandibular tooth preceding the maxillary.

6. *Third molar eruption.*—The third molars erupt so late that they are almost solely a problem of the adult. It has been contended that the eruption of the third molars forces the dentition forward, causing crowding of the teeth, but the evidence to support this theory is unconvincing.

The Origin of Malocclusion

Malocclusions are of three general types: skeletal or osseous (genetic), dental, and functional or muscular.

1. The mixing of races seen on this continent has resulted in many genetic combinations not favorable to the production of harmonious facial development. Many malocclusions are due to unfavorable or disharmonious bone growth. The commonest problems are mandibular retrognathism,

mandibular hypertrophy and asymmetry of the face. In addition, there may be insufficient bony support for the dentition, i.e., the bones are not big enough for the teeth, or vice versa, the teeth are too large for their bony base.

2. Improper care of the primary dentition may result in premature loss of deciduous teeth, permitting drifting of the permanent teeth or tooth buds. Pernicious pressure habits can also cause malpositioning of teeth.

3. A malrelationship of the mandible causes malocclusion. Most functional malrelationships of the mandible are due to reflexes learned to avoid malpositioned teeth. For example, functional mandibular retraction is frequently seen when the maxillary dental arch is narrowed. The muscles simply retrude the lower jaw to permit occlusion with a wider portion of the maxilla.

It is thus seen that not all malocclusions have a similar etiologic history. Because of the variance in origin, the prognoses are not the same. It is much easier to correct tooth malpositions and functional malrelationships due to muscle reflexes than it is to overcome inherent genetic patterns of bone growth. Early diagnosis is the first step in minimizing the effects of malocclusion.

HOW THE TEETH GROW

The entire process by which a human being gets his teeth constitutes a highly interesting interaction of the ectodermal and mesodermal tissues throughout the early years of life.

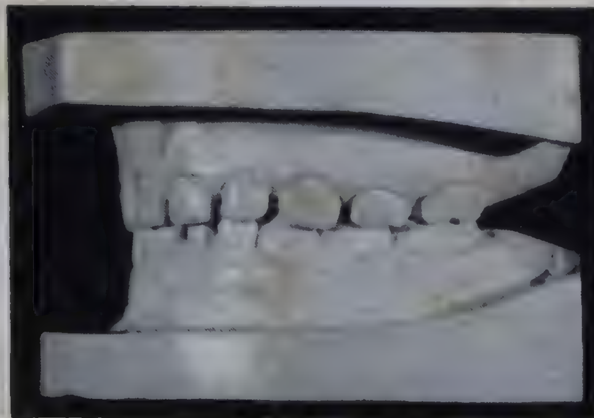
Precisely, the basal layer of cells of the stratified squamous epithelium lining the oral cavity begin to proliferate rapidly about the 34th day of embryonic life and develop a ridge along the free margins of the jaws, the dental lamina. About the 6th week of intrauterine life, 10 ovoid swellings appear at intervals about this ridge of ectodermal tissue, the tooth buds of the 10 primary teeth (Fig. 64). Continuing rapid proliferation of the epithelial cells leads to the development of a budlike "invasion" of the underlying mesodermal connective tissue. A concomitant stimulation of this embryonic connective tissue leads to a rapid proliferation of its cells which produces the dental papilla, the organ responsible later for the formation of the dentin and pulp. The continued proliferation of the epithelium produces a caplike enamel organ surrounding the outer end of the dental papilla.

Further proliferation of the epithelial cells at the deep margins of the

cap leads to the development of a bell-shaped enamel organ (Fig. 65). The innermost layer of cells (the interior of the bell) later will produce the specialized tall, hexagonal, columnar cells, the ameloblasts, which will lay down the enamel matrix. A large portion of the dental papilla becomes enclosed in this invaginated bell, and the outermost layer of its peripheral cells then undergo differentiation to the tall, columnar odontoblasts. The basement membrane separating the layer of ameloblasts of the enamel organ from the odontoblasts of the dental papilla later becomes the dento-enamel junction of the calcified crown. The remaining embryonic connective tissue of the interior of the dental papilla becomes the dental pulp. The outer layer of enamel epithelium of the bell-like ectodermal invasion and the stellate cells which separate it from the inner specialized layer of ameloblasts begins to serve as a nutritive mechanism as soon as calcification begins. This occurs between the 4th and the 6th month of uterine life at the dentoenamel junctions of the 20 primary teeth. It then reduces to a thin layer of cells on the completion of the enamel, the reduced enamel epithelium. The remnants of the remaining ameloblasts degenerate to a thin, acellular, chitinous membrane on completion of the enamel, but the layer of odontoblasts remains around the periphery of the pulp as a permanent mechanism for the formation of secondary dentin.

Following the laying down of dentin and enamel, activity of the deepest margins of the invaginated bell (the epithelial root sheath) initiates the formation of the root or roots and molds their shape. Continued extension of the original ridgelike dental lamina lingually and distally leads similarly to a cycle of developmental events which produces the permanent teeth. The tooth germs of the succedaneous permanent teeth appear lingually to those of the primary teeth from the 5th month in utero (central incisors) to 10 months after birth (second bicuspids), and the tooth germs of the three permanent molars appear progressively distal to that of the second primary molar from 4 months of fetal life (first molar) to the 4th or 5th year of life (third molar).

With the development of the roots of the primary teeth, the crowns move occlusally until the reduced enamel epithelium fuses with the oral epithelium, the epithelium over the tips of the cusps of the crowns degenerates and the crown gradually erupts into occlusion with its opponent from the opposite arch. The remnant of the inner layer of cells of the bell, now a thin degenerated membrane, the enamel cuticle, gradually wears away and the sole remaining evidence of the original fetal invasion of



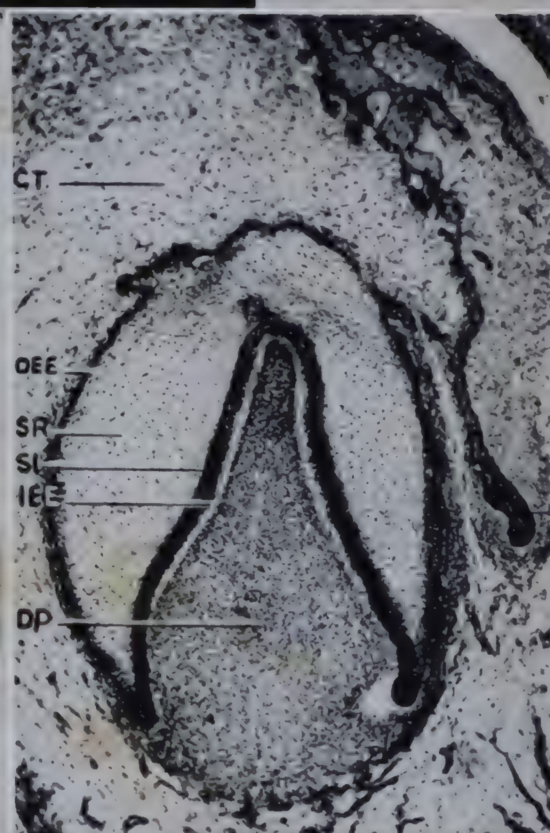
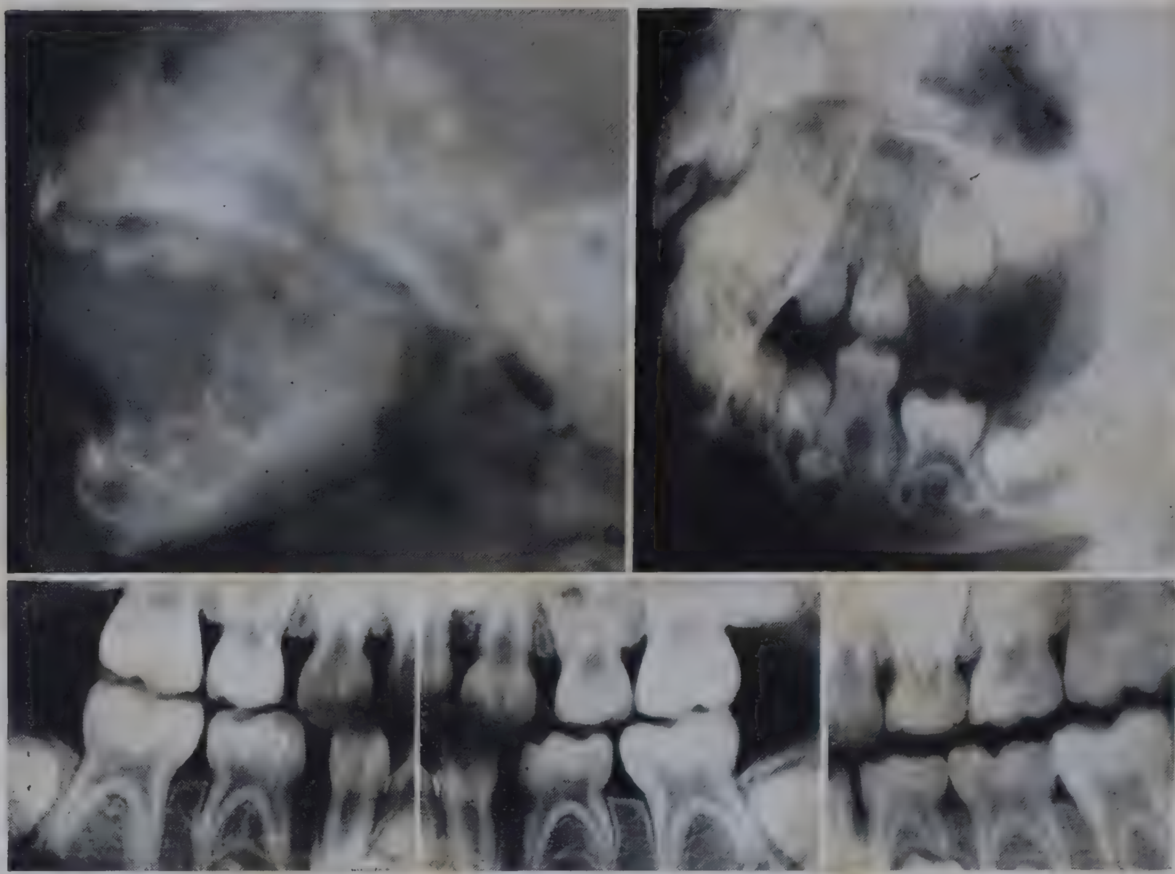


Fig. 63 *(above)*.—Normal primary occlusion; age 5 years.

Fig. 64 *(below left)*.—Section through mouth of human embryo about 6 weeks old. Opposing collections of cells in upper and lower jaws are the beginnings of primary tooth buds. Invagination has already started. *T*, tongue; *A*, arch of mandible; *UJ*, upper jaw; *LJ*, lower jaw.

Fig. 65 *(below right)*.—Section through developing tooth—advanced "bell" stage—in fetal mandible at about 4 months. By the time of birth, the crowns of all 20 primary (deciduous) teeth are in the process of calcification and enough inorganic calcium has been deposited to permit their detection on x-ray films (see Fig. 66). *CT*, connective tissue of mandible; *OEE*, outer enamel epithelium; *SR*, stellate reticulum; *SI*, stratum intermedium; *IEE*, inner enamel epithelium; *DP*, dental pulp. It should be remembered that both primary (deciduous) and secondary (permanent) teeth are fully formed and their crowns calcified months to years before they erupt.



Figs. 66–69.—Stages in development and eruption of teeth. To a certain extent, a physician, like a veterinarian, can tell the age of his patient by looking at the teeth. X-rays help in this estimation.

Fig. 66 *(above left)*.—Newborn; lateral radiograph of jaws. Enough inorganic calcium has matured in crowns of all 20 primary teeth so that incisal and occlusal surfaces are outlined.

Fig. 67 *(above right)*.—Age 16 months; lateral radiograph of jaws. Primary first molars have erupted (12-14 months); primary cuspids are erupting and crowns of their permanent successors are about one-fifth calcified. Primary second molars will erupt to complete preschool dentition at 20-24 months. Crowns of first and second bicuspids (position indicated by radiolucent follicles between roots of lower primary molars) have not begun to calcify, and crowns of first permanent molars are about one-third calcified.

Fig. 68 *(below left)*.—Age 2½; left and right bite-wings of girl, showing posterior primary dentition completely erupted. Crowns of first bicuspids have begun calcification (1¾-2 years); those of second bicuspids should be ready to begin calcification; crowns of first permanent molars are just completing calcification, and crowns of second permanent molars (not shown) are ready to begin calcification.

Fig. 69 *(below right)*.—Age 8; right bite-wing of boy, showing (left to right) primary cuspids, primary first and second molars and first permanent molars in occlusion. Crowns of first and second bicuspids (root-wise to primary molars) and of permanent second molars (not shown) are completely calcified. This child has developed beyond the level (third molars excepted) where tooth crowns can be affected by intake of vitamins D or C, calcium and phosphorus.

ectodermal tissue, now returned to the oral cavity, is the enamel, without cells, without nerve supply, without blood supply, hence, without any direct systemic connection. As a child grows, the crowns of the permanent teeth develop, the roots of the primary teeth resorb, the permanent teeth, both succedaneous and molars, erupt, occlusion of the permanent teeth in the two arches establishes and the attrition of the enamel of the crowns begins.

This life cycle of dental histophysiologic events now may be summarized briefly into six periods for diagnostic purposes: (1) growth; (2) calcification and maturation; (3) eruption of primary teeth; (4) resorption of roots of primary teeth; (5) eruption of permanent teeth, and (6) attrition. The period of growth may be divided further into five distinct but overlapping periods of rapid change prior to the second period of the cycle, the period of calcification and maturation. These five periods are (1) initiation, the development of the dental lamina and tooth buds; (2) proliferation, the rapid growth of cells by which the initiated tooth develops through the stages of the bud, cap and bell, along with the concomitant changes of the dental papilla; (3) histodifferentiation, the development of the specialized cells, the ameloblasts and odontoblasts; (4) morphodifferentiation, the stage of development of final characteristic contour and size of the crowns of the various teeth; and (5) apposition, the deposition of the matrix of the enamel progressively outward along the length of the ameloblast from the dentoenamel junction. This activity terminates in the external contour of the crown and the deposition of the matrix of the dentin inward, an activity which reduces the size of the pulp by reducing the size of the pulpal chamber. For a more thorough study of the development and histophysiology of teeth, it is suggested that one read Schour and Massler.[9, 10]

THE TEETH IN CLINICAL APPRAISAL OF A CHILD'S DEVELOPMENT

Since the development and eruption of teeth is a part of a child's total development, a dental developmental schedule has been utilized as one index of growth and maturation during childhood. Probably insufficient serial studies have been devoted to the development of teeth, particularly of the preschool dentition, to establish an average or norm for a number of the racial groups and geographic areas found in the United States. The "chronology of the human dentition," developed from a limited histologic and radiographic study of young human skulls in 1933 by Logan and

TABLE 46.—CHRONOLOGY OF THE HUMAN DENTITION

Tooth	Hard Tissue Formation Begins	Amt. of Enamel at Birth	Enamel Completed	Eruption	Root Completed	Exfoliation
Primary						
Maxilla						
Central	4 mo. in utero	Five-sixths	1½ mo.	7½ mo.	1½ yr.	6–7 yr.
Lateral	4½ mo. in utero	Two-thirds	2½ mo.	9 mo.	2 yr.	7–8 yr.
Cuspid	5 mo. in utero	One-third	9 mo.	18 mo.	3¼ yr.	10–12 yr.
1st mo.	5 mo. in utero	Cusps united	6 mo.	14 mo.	2½ yr.	9–11 yr.
2d mo.	6 mo. in utero	Cusp tips still isolated	11 mo.	24 mo.	3 yr.	10–12 yr.
Mandible						
Central	4½ mo. in utero	Three-fifths	2½ mo.	6 mo.	1½ yr.	6–7 yr.
Lateral	4½ mo. in utero	Three-fifths	3 mo.	7 mo.	1½ yr.	7–8 yr.
Cuspid	5 mo. in utero	One-third	9 mo.	16 mo.	3¼ yr.	9–12 yr.
1st mo.	5 mo. in utero	Cusps united	5½ mo.	12 mo.	2¼ yr.	9–11 yr.
2d mo.	6 mo. in utero	Cusp tips still isolated	10 mo.	20 mo.	3 yr.	10–12 yr.
Permanent						
Maxilla						
Central	3–4 mo.	....	4–5 yr.	7–8 yr.	10 yr.	
Lateral	10–12 mo.	....	4–5 yr.	8–9 yr.	11 yr.	
Cuspid	4–5 mo.	....	6–7 yr.	11–12 yr.	13–15 yr.	
1st bic.	1½–1¾ yr.	....	5–6 yr.	10–11 yr.	12–13 yr.	
2d bic.	2–2¼ yr.	....	6–7 yr.	10–12 yr.	12–14 yr.	
1st mo.	At birth	Sometimes trace	2½–3 yr.	6–7 yr.	9–10 yr.	
2d mo.	2½–3 yr.	....	7–8 yr.	12–13 yr.	14–16 yr.	
3d mo.	7–9 yr.	....	12–16 yr.	17–21 yr.	18–25 yr.	
Mandible						
Central	3–4 mo.	....	4–5 yr.	6–7 yr.	9 yr.	
Lateral	3–4 mo.	....	4–5 yr.	7–8 yr.	10 yr.	
Cuspid	4–5 mo.	....	6–7 yr.	9–10 yr.	12–14 yr.	
1st bic.	1¾–2 yr.	....	5–6 yr.	10–12 yr.	12–13 yr.	
2d bic.	2¼–2½ yr.	....	6–7 yr.	11–12 yr.	13–14 yr.	
1st mo.	At birth	Sometimes trace	2½–3 yr.	6–7 yr.	9–10 yr.	
2d mo.	2½–3 yr.	....	7–8 yr.	11–13 yr.	14–15 yr.	
3d mo.	8–10 yr.	....	12–16 yr.	17–21 yr.	18–25 yr.	

TABLE 47.—RADIOGRAPHIC DETERMINATION OF SERIAL DEVELOPMENT OF MANDIBULAR POSTERIOR TEETH

AGE LEVEL	CORONAL CALCIFICATION	ERUPTED	COMPLETION OF ROOTS
Birth	*Primary* 3/5, incisors 1/3, cuspids Tips of cusps calcified in united ring, 1st molar Tips of cusps calcified, still isolated in separate centers of calcification, 2d molar *Permanent* Sometimes traces in tips of mesial cusps, 1st molars	None	None
9–10 mo.	*Primary* Enamel completed all teeth *Permanent* Tips of cusps calcified, still isolated, 1st molars Trace of incisal edges, centrals, laterals Tips of cuspids	*Primary* Centrals Laterals	None
1 yr.	*Permanent* (balance of table) Cusps united in ring, 1st molars 1/5–1/4, centrals, laterals 1/7–1/6, cuspids	Add *primary* 1st molars	None
16–18 mo.	1/3, 1st molars 1/4–1/3, centrals, laterals 1/6–1/5, cuspids Tip of cusp, some 1st bicuspids	Add *primary* cuspids	*Primary* Centrals and laterals completed
2 yr.	1/2–2/3, 1st molars 2/5–1/2, centrals, laterals 1/4, cuspids Tips of cusps, all 1st bicuspids Tips of cusps, some 2d bicuspids	Add *primary* 2d molars	None added
2½–3 yr.	Completed, 1st molars 2/3, centrals, laterals 3/8, cuspids 1/2, 1st bicuspids 1/6, 2d bicuspids Trace, tips mesial cusps, 2d molars	Add none	*Primary* 1st and 2d molars completed Some cuspids completed
4½ yr.	3/4–5/6, 1st bicuspids 5/8–3/4, 2d bicuspids 5/8–3/4, cuspids 1/3, 2d molars Completed, centrals and laterals	Add none	*Primary* All cuspids completed *Permanent* (balance) 1/3, 1st molar
6–7 yr.	Completed, 1st and 2d bicuspids, cuspids 2/3, 2d molars	*Permanent* (balance) 1st molars Centrals	3/8–1/2, 1st molars
7–8 yr.	Completed, 2d molars Trace tips of cusps, some 3d molars	Add laterals	1/2–2/3, 1st molars 6/7, centrals 3/4, laterals Variable amt., 1st, 2d bicuspids, cuspids

TABLE 47.—Radiographic Determination of Serial Development of Mandibular Posterior Teeth (*Cont.*)

Age Level	Coronal Calcification	Erupted	Completion of Roots
9–10 yr.	Beginning calcification, most 3d molars	Add most cuspids, many 1st bicuspids	Completed centrals, laterals, 1st molars 1/2, 1st bicuspid 1/3, 2d bicuspid 1/4, 2d molar
12 yr.	1/4–5/6, 3d molars	Add 2d bicuspids, most 2d molars	Completed, many cuspids, 1st bicuspids 2/3, 2d bicuspids 1/3, 2d molars

Kronfeld[6] and later modified by the clinical experience of McCall and Schour,[1] has been utilized so extensively as an index of development, however, that it has been reproduced in outline form (Table 46).

For clinical estimation of dental ages, it is suggested that this table be used in connection with an examination of the child's mouth to ascertain the number of erupted and exfoliated teeth along with a careful examination of the development of the posterior mandibular teeth as exhibited in a size no. 2 posterior bite-wing or in a lateral jaw radiograph. Using the usual "standard"-equipped, dental x-ray machine and Radia-tized film, a diagnostic bite-wing radiograph can be secured by placing the film pack in the child's mouth, having him close his primary molars on the wing turned down at right angles to the film, and exposing the film at 8 degrees downward (face of the machine parallel with the buccal surfaces of the posterior teeth) for 1¾–2½ seconds during the period of the preschool dentition, 2½ to 3 seconds during the period of the mixed dentition, and 3 to 3½ seconds during the period of the young permanent dentition. A diagnostic 5 × 7 in. lateral jaw radiograph may be secured with the film adjusted in a cassette equipped with "Detail" intensifying screens and the cassette placed in the head-rest of a dental chair, the child's chin elevated and head rotated until his nose is approximately ¼ in. from the cassette and the film exposed at 17 degrees upward for ¾–1 second, with the tip of the cone in contact with the patient ½ in. inferiorly and posteriorly to the angle of the jaw on the side of the mandible opposite to the teeth being diagnosed; and the face of the machine parallel with the film holder.

Average dental development of children, beginning with the full-term infant at birth, is shown in Figures 66-69 and summarized in Table 47.

TABLE 48*A*.—Age Norms for Mandibular Teeth for Boys

Age	Central Incisor $\overline{1\vert 1}$	Lateral Incisor $\overline{2\vert 2}$	Cuspid $\overline{3\vert 3}$	1st Bicuspid $\overline{4\vert 4}$	2d Bicuspid $\overline{5\vert 5}$	1st Molar $\overline{6\vert 6}$	2d Molar $\overline{7\vert 7}$	3d Molar $\overline{8\vert 8}$	All Teeth Excl. 3d Molar	All Teeth Incl. 3d Molar
4	**71.5**	**68.6**	42.7	34.8	20.4	**64.4**	20.8	0	323.2	323.2
5	75.5	71.9	51.5	43.0	33.1	71.5	30.8	0	377.3	377.3
6	79.5	76.1	**57.4**	51.6	42.7	76.9	40.7	0	424.9	424.9
7	88.8	83.2	65.9	**60.8**	53.6	83.3	51.5	8.8	487.1	495.9
8	95.0	90.4	73.5	68.8	**62.4**	89.5	**59.4**	14.2	539.0	553.2
9	95.9	95.4	79.7	75.4	70.3	94.5	66.8	18.1	578.0	596.1
10	98.5	98.5	85.5	81.1	76.5	97.9	73.2	20.9	611.2	632.1
11	100.0	100.0	90.9	87.8	83.4	99.0	78.9	27.6	640.0	667.6
12	100.0	100.0	95.8	94.1	89.5	99.5	84.6	35.2	663.5	698.7
13	100.0	100.0	98.5	96.9	93.7	100.0	89.3	44.9	678.4	723.3
14	100.0	100.0	99.5	98.8	96.5	100.0	93.9	53.9	688.7	742.6
15	100.0	100.0	100.0	100.0	99.0	100.0	96.6	**62.8**	695.6	758.4
16	100.0	100.0	100.0	100.0	100.0	100.0	99.9	71.1	699.9	771.0
17	100.0	100.0	100.0	100.0	100.0	100.0	100.0	76.1	700.0	776.1
18	100.0	100.0	100.0	100.0	100.0	100.0	100.0	79.3	700.0	779.3

TABLE 48*B*.—Age Norms for Mandibular Teeth for Girls

Age	Central Incisor $\overline{1\vert 1}$	Lateral Incisor $\overline{2\vert 2}$	Cuspid $\overline{3\vert 3}$	1st Bicuspid $\overline{4\vert 4}$	2d Bicuspid $\overline{5\vert 5}$	1st Molar $\overline{6\vert 6}$	2d Molar $\overline{7\vert 7}$	3d Molar $\overline{8\vert 8}$	All Teeth Excl. 3d Molar	All Teeth Incl. 3d Molar
4	**69.3**	**66.9**	56.5	39.1	28.6	**70.2**	26.7	0	357.3	357.3
5	75.5	71.7	**61.8**	50.5	38.3	74.4	39.4	0	411.6	411.6
6	84.5	79.2	67.1	**60.2**	47.1	80.3	50.3	23.5	468.7	492.2
7	93.4	86.0	72.4	67.2	**57.6**	86.1	**60.4**	18.8	523.1	541.9
8	98.8	94.7	77.9	72.9	65.6	92.7	67.2	21.1	569.8	590.9
9	100.0	99.5	83.4	79.6	73.2	98.2	73.5	23.2	607.4	630.6
10	100.0	100.0	90.4	84.8	79.2	99.7	78.6	32.9	632.7	665.6
11	100.0	100.0	96.4	91.7	85.0	100.0	82.6	37.7	655.7	693.4
12	100.0	100.0	99.7	97.1	91.9	100.0	88.6	47.7	677.3	725.0
13	100.0	100.0	100.0	100.0	93.7	100.0	95.0	**58.5**	688.7	747.2
14	100.0	100.0	100.0	100.0	93.8	100.0	97.4	65.6	691.2	756.8
15	100.0	100.0	100.0	100.0	96.5	100.0	97.8	69.9	694.3	764.2
16	100.0	100.0	100.0	100.0	99.7	100.0	98.7	75.6	698.4	774.0
17	100.0	100.0	100.0	100.0	100.0	100.0	99.0	80.3	699.0	779.3
18	100.0	100.0	100.0	100.0	100.0	100.0	100.0	80.5	700.0	780.5

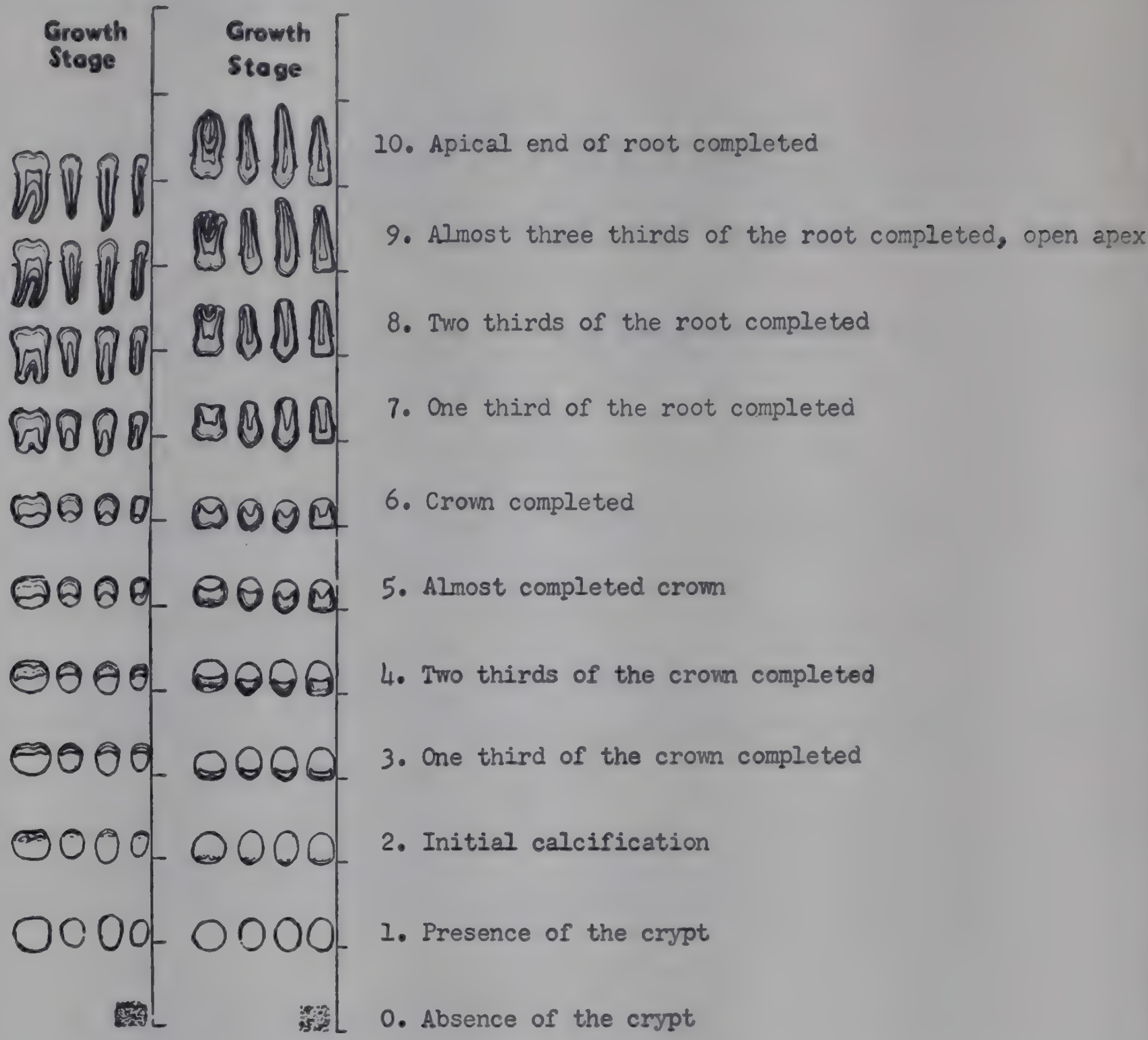


FIG. 70.—Drawings made from roentgenograms of developing permanent teeth, to be studied in conjunction with Table 48. Beginning with stage 1 (of Nolla's 10 stages assigned to developing teeth), in which the tooth bud is hardly more than a ring of cells, the tooth develops to stage 10, where it is complete. Note that the crown develops much sooner than the root, as seen in Figure 67, where the 6 year molar has a well developed crown but no roots as yet. A value of 60 (6 in the drawings) indicates that the crown of the particular tooth is complete.

Nolla[8] recently completed a serial radiographic study (by yearly increments of growth) of 25 boys and 25 girls at the University of Michigan's Elementary School (Table 48). The chart used to define 10 stages of dental development is shown in Figure 70. Beginning her study of the 50 children at 4 years (48 months) of age, Nolla computed the percentage of completion for the teeth through 18 years (216 months) (Table 48). A value of 60.0 indicates that development of the crown is complete (see values in

bold face). Girls, it will be noted, are about one year ahead of boys in dental development but advance at the same annual rate.

Returning to the chronology of dentition (Table 46), a few examples may be cited to illustrate the use of such a table. Individual children may be expected to vary considerably from any average established for a population, and for this reason considerable advance or retardation should be permitted as a range of normality. The premature infant may be expected to be considerably retarded, if development is measured from date of birth, whereas the full-term infant with a family history of early dental development may be born with the two mandibular incisors erupted or erupting. Unless these two prematurely erupted incisors are obviously malformed supernumerary teeth and the diagnosis is confirmed radiographically, they should *not* be extracted.

If one who is studying a radiograph of a child's mandible notes that the crown of the first permanent molar is completed, the crowns of the second bicuspid and the second permanent molar have just begun to exhibit calcification and the large buccal cusp of the first bicuspid exhibits distinct calcification, he concludes that this child has a dental age of 2½–3 years. If a mother asks whether a severe illness at 6 years of age caused the irregular, hypoplastic incisal edges of her daughter's newly erupted centrals, the answer obviously is "no"; the incisal edges of the mandibular incisors are calcified by 16–18 months and the entire crowns by 4–5 years. The diagnostician probably should hesitate to conclude that the biscuspids, particularly the second, are congenitally missing on the basis of radiographic evidence at 4–5 years. If at 5 years of age, however, the area normally occupied by the follicle of the bicuspid exhibits trabeculated bone, one may conclude that the tooth *is* missing; if, on the other hand, a translucent area can be detected, one probably should wait one year further for evidence of calcification, since a number of bicuspids are extremely late in their development.

THE DENTAL ANOMALIES

Interference during any stage of the growth of teeth, as well as interferences during the periods of calcification, the eruption or the exchange of the two dentitions, will lead to anomalous development which may involve one or more teeth but not necessarily the child's occlusion. For example, a disturbance during initiation may produce too many or too few teeth:

during proliferation, extra cusps or roots, twinning, fusion and dental tumors; during histodifferentiation, odontomas and dentinogenesis imperfecta (opalescent dentin); during morphodifferentiation, peg-shaped teeth, Hutchinson's incisors and unusually small or unusually large teeth; during apposition, hypoplasia of tetany, rickets and heredity; during calcification, mottled enamel, vital staining and amelogenesis imperfecta; and during eruption, impaction, ectopy and ankylosis. Most of these anomalies gradually are being shown to exhibit a familial pattern of development.

Probably a more useful classification of the dental anomalies can be made on the basis of their characteristic appearance rather than on the period of their initiation. These deviations in development, then, may be grouped an anomalies of number, of shape, of texture and of position. It would be beneficial to the children concerned if most of these anomalies could be detected early and the children referred promptly to a children's dentist or an orthodontist.

1. Anomalies of number.—Of the missing teeth, the absence of maxillary lateral incisors and the second bicuspids most frequently is detected in children. The absence of either creates a problem of occlusion. Supernumerary teeth occur most often in the midline of the maxillary arch where they interfere with eruption and alinement of the normal incisors.

A few children exhibit the bizarre condition known as ectodermal dysplasia, in which many surface structures may be involved as a syndrome of ectodermal deviations. Along with variations or complete absence of sweat and sebaceous glands, adult hair, eyebrows, eyelashes and finger-nails, the teeth may be totally or partially missing. Those teeth which do erupt are characteristically conoid.

2. Anomalies of shape.—Not infrequently the maxillary laterals fail to develop as typical incisors but erupt as small, cone-shaped, "peg" teeth. The crowns of the late-maturing bicuspids even may not resemble teeth; hutchinsonian permanent incisors and molars have been described in many textbooks; a number of anterior permanent teeth may erupt malformed from a traumatic episode which has involved the primary predecessor; attention already has been called to the conoid teeth that accompany ectodermal dysplasia; and it should be kept in mind that extensive irradiation of the jaws during the period of growth of the teeth halts dental development at the particular level of development reached.

3. Anomalies of texture.—Two hereditary anomalies of development

alter the structure of teeth in a unique pattern. One anomaly, involving odontoblasts, produces dentinogenesis imperfecta or hereditary opalescent dentin. Most of the affected teeth exhibit a peculiar amber color, abrade early and extensively and, radiographically, exhibit roots which appear rather small for their crowns but with highly calcified or completely missing pulpal chambers and root canals. Amelogenesis imperfecta, on the other hand, involves maldevelopment by the ameloblasts. Such teeth develop and erupt (infrequently they fail to erupt) with very little, imperfectly formed enamel. The frail enamel stains and abrades or wears until the teeth become quite disfiguring. The only solution usually is extraction of the teeth and preparation of complete dentures early in life. Rarely are either of these conditions accompanied by caries; in fact, most of the involved members of the families studied at the School of Dentistry of the University of Michigan have submitted samples of saliva which provide negative counts of lactobacilli.

4. *Anomalies of position.*—Radiographic examination frequently detects a first permanent molar erupting ectopically into the distal roots of the second primary molar. Unless the dentist interferes at an early period, pressure of its crown results in resorption of the roots of the primary molar, premature exfoliation of that tooth and serious loss of space in the arch. In another type of anomalous development, a number of children are found with the roots of the primary molars apparently ankylosed while the bony arches increase in their occlusal dimension due to an elaboration of the alveolar bone which provides support for the developing permanent teeth. Such ankylosed primary molars actually have been found completely submerged. A dental anomaly of position also accompanies the syndrome of craniocleidodysostosis; the primary teeth are retained into adulthood and the permanent teeth remain unerupted.

Since most of the dental anomalies which have been described have deleterious implications for a child's appearance or the alinement of his teeth, it appears pertinent to re-emphasize their early detection and the referral of the patient for treatment. It is of interest to note, too, that the anomalies of dental development may accompany anomalous development in other areas of a child's body. Amelogenesis imperfecta, for example, has been associated with failure of the permanent teeth to erupt, tremendous overgrowths of the fibrous tissue of the gingivae, degenerative macules of the retina and the annoying dermal condition, epidermolysis bullosa.

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An Outline of Abnormal Growth

Strictly speaking, any outline of abnormal growth must include almost all of the many congenital anomalies and dystrophies, for they represent abnormalities of growth. Our outline, however, is limited primarily to the aberrations of statural growth in infancy and childhood.

In the preceding chapters the major factors that influence growth in a normal manner have been considered. Much of our knowledge has resulted from studies of abnormal subjects. This chapter is included mainly to help the reader to a better understanding of the potentialities of growth and how growth may deviate from the usual pattern; it is not meant to be an exhaustive treatise.

DWARFISM

Talbot[12] has used the term dwarfism to designate any child moderately or conspicuously shorter than 90 per cent of children in the community of the same chronological age. Retarded growth may be due either to a slow rate or to an unusually short period of growth.[10, 11]

I. Bone Diseases

1. *Classic chondrodystrophy (achondroplasia).*—This is apparently a hereditary condition following in general the character of a mendelian recessive type in most instances. The primary pathologic changes are limited to parts of the skeleton which develop from cartilage. The cartilage cells mature less rapidly than the normal and the patterns of growth are irregular. The disturbance of proportion and the retardation of growth begin in an early period of intrauterine life.

The major clinical feature is the pronounced shortness of all of the extremities and consequent dwarfism. The skull is frequently large.

Roentgenograms show that the bones of the arms and legs are short and wide and have a thickened cortex. The distal portion of the metaphyses is broad and irregular in varying degrees. The epiphyseal ossification centers may appear later than normally. Blood chemistry and B.M.R. are normal.

2. *Micromelia; phocomelia.*—In micromelia there is abnormal shortness of the extremities without any of the other changes noted with chondrodystrophy. Development is often incomplete. In phocomelia there is congenital absence of distal segments of the arms or legs or both. In some cases all extremities are missing, and subjects are born with only a trunk and head.

3. *Lipochondrodystrophy (Hurler's syndrome).*—This also is apparently a hereditary condition of a recessive type and is congenital. Washington[14] believes it should be grouped with the Niemann-Pick syndrome. Pathologic changes include slowness and irregularity of cartilage growth in the long bones and vertebrae. In the ganglion cells of the brain are found granular deposits of a lipid-like substance. In some cases this substance has also been found in the liver, spleen, kidneys, myocardium and other organs.

Clinically the condition is characterized by dwarfed stature, with shortening of the neck and trunk, kyphosis, coarseness of the facial features, limitation of joint movements with resultant clawlike hands and enlargement of the liver and spleen with consequent protrusion of the abdomen. Clouding of the cornea and mental changes may be present. Roentgenograms of the hands and long bones show typical changes. The appearance of ossification centers is usually delayed.

4. *Osteochondrodystrophy (Morquio's syndrome).*—This disease closely resembles Hurler's syndrome, just described. It is genetically determined in many cases. It differs clinically from Hurler's syndrome in the following respects: the liver and spleen are not enlarged, the hands are not clawlike, the cornea is rarely involved and there are seldom mental changes.

5. *Dyschondroplasia.*—In this group McCune[10] has included several types. Those resulting in dwarfism are Ollier's disease, in which multiple enchondromas of the tubular bones are irregularly distributed and characteristically produce shortening deformities of the affected bones, and osteopetrosis or Albers-Schönberg disease, characterized by persistence of the calcified cartilaginous matrix and consequent marked increase in

density on roentgenograms. In the latter disease there is severe anemia due to crowding of the bone marrow and, usually, splenomegaly and hepatomegaly. Both are believed to be hereditary in origin. In neither is the shortness of stature very pronounced.

6. *Osteogenesis imperfecta.*—Dwarfism in this disease is the result of numerous fractures of the lower extremities with impaction, angulation and overlapping of fragments. The disease takes two forms, one present at birth and one that appears later in life. The former is more apt to cause dwarfism. The pathologic change is found in the osteoblasts, which are few in number and decreased in activity, with resultant rarefied trabeculation.

The clinical picture is that of deformed extremities due to fracture, a skull of eggshell consistency (crane à rebord) and blue scleras. Roentgenograms reveal diminished density of bones and thin shafts. The disease is frequently familial.

7. *Rickets.*—Rickets is caused by an inadequate intake of vitamin D, resulting in poor absorption of calcium and failure of calcification of the organic matrix in the growing bones. The blood reveals a lowered value for serum phosphorus and a normal or lowered calcium content. As we have already seen (p. 205) the product of serum calcium and serum phosphorus must be above a certain level before calcium salts are deposited. Even though osteoblastic activity is increased in rickets, as shown by an increased alkaline phosphatase serum level, it will not free enough phosphorus on the growing bone surface to exceed the solubility product of the calcium salt. Consequently calcium is not incorporated into the osteoid tissue. The resulting softness of the bones leads to the characteristic deformities and consequent reduction in stature. Roentgenologic examination reveals the demineralization of bone and the widened space between the epiphyseal plate and the diaphysis. This space represents osteoid tissue which normally would be undergoing active mineralization.

An interesting condition is that called "refractory rickets." Children with this disease have persistence of the rachitic stigmas long after the usual type has healed either as a result of therapy or spontaneously. The roentgenologic changes are pronounced. Deformities are often severe. The blood has a very low phosphorus content, sometimes below 2.0 mg. per cent, and a high phosphatase value, but usually a normal or only slightly decreased calcium level. The cause of the condition is not known. The term "refractory" has been used because ordinary amounts of vitamin

D have no effect on bone mineralization. Doses exceeding 500,000 units of vitamin D daily may be necessary to put the patient in positive calcium and phosphorus balance and insure normal calcium deposition in bone.[6]

8. *Diseases of the spine.*—In this group may be mentioned hemivertebra, which may sufficiently shorten the trunk to cause dwarfism. Pott's disease may cause shortening of the vertebral column, and various injuries may also be included.

II. Generalized Diseases

Many different diseases of infants and children may cause either temporary or permanent retardation of growth. Only a few will be outlined here.

1. *Galactosuria.*—This is one of the so-called inborn errors of metabolism. Its mechanism is poorly understood. It is a relatively rare congenital disease accompanied by retarded growth in the more severe cases. Hepatomegaly is often pronounced, owing to cirrhosis. As a result, glycogen storage is reduced, causing hypoglycemia of such degree that it may represent the most prominent physiologic abnormality and cause the major symptomatology. It is probably this disturbed carbohydrate physiology which accounts for the retarded growth. Galactosuria and galactosemia are universal findings in these cases.

2. *Cystinuria.*—This is another of the inborn errors of metabolism in which heredity appears to play an important role. The condition may be severe or mild; it is only in the former that disturbances of growth occur. There may be deposits of cystine in various organs of the body, and renal calculi are common in the more severe forms. It is almost certainly this last complication, leading to renal insufficiency, that retards growth.[2]

3. *Glycogen storage disease (von Gierke's disease).*—This disorder may take two forms. (*a*) The hepatic form is characterized by hepatomegaly due to excessive glycogen deposits, hypoglycemia, acetonuria, lipemia and failure of the blood sugar content to rise after the injection of epinephrine. The fault lies in the enzyme system responsible for the mobilization of glycogen from the liver and its release as glucose into the blood stream. The glycogen deposits themselves do not appear to be abnormal. Hypoglycemia may be an important part of the syndrome clinically, and the child may show severe hypoglycemic reactions such as convulsions and shock. Stature may be affected as the result of the disturbed carbohydrate metabolism and not fundamentally of bone changes. (*b*) The other form

of glycogen storage disease primarily affects the heart. Cardiomegaly and disturbed conduction result from markedly increased glycogen stores. Children with this type do not display the changes in the blood typical of the hepatic form. They usually die very early in life. The coexistence of the two forms of the disease has not been reported.

4. *Diabetes mellitus.*—Children with severe and poorly controlled diabetes may show a reduction in both height and weight.[3] In refractory diabetes (Mason's disease) dwarfism may be pronounced. With improved methods of control, including close attention to adequacy of diets, one rarely sees pronounced statural abnormalities in diabetic children today. Some authors have stated that the height of the average diabetic child is greater than normal at the time of onset of the disease, but other workers in the field have published contradictory figures.

5. *Reticuloendotheliosis (lipoidoses).*—With Niemann-Pick, Hand-Schüller-Christian and Gaucher's diseases, abnormalities in growth and mental development are common. The prognosis for long life is poor in any of these diseases, although occasionally patients with the Hand-Schüller-Christian syndrome live into adult life and are frequently dwarfed in a symmetrical manner due to hypopituitarism from involvement of the gland or related structures.

6. *Nutritional privation.*—Stunted growth from poor nutrition may be on either a quantitative or a qualitative basis. Some of the aspects are discussed in Chapter 11. Psychologic anorexia has been known to result in reduced stature in some children.

7. *Chronic infections.*—A large number of diseases could be listed under this classification. A few examples are hookworm infestation, malaria, dysentery, pulmonary disease, syphilis and osteomyelitis. Gardiner-Hill[7] stated that such diseases may cause a premature "senescence of growing cartilage" with calcification. Growth failure may be either temporary or permanent.

III. Organic Disorders

McCune[10] classified in this group the diseases causing small stature in which a disturbance is primarily located in a single organ or organ system.

1. *Congenital heart disease.*—Reduction of stature here depends largely on the severity of the condition. The more common conditions related to poor growth are pulmonary stenosis, patent ductus arteriosus

when associated with other cardiac anomalies, transposition of the great vessels with septal defects, and coarctation of the aorta. In nearly all of these, the failure of growth, when present, is believed to be due to anoxia hampering cellular metabolism.

2. *Hepatic insufficiency.*—Prolonged hepatic insufficiency, as in cirrhosis and congenital atresia of the biliary passages, notoriously slows growth and may be associated with rickets due to poor absorption of fat-soluble vitamins.

3. *Pancreatic insufficiency.*—Children who have the celiac syndrome and pancreatic cystic fibrosis may simply remain small without showing rickets, or rickets may be superimposed on the primary disease. In both diseases there is poor absorption of ingested foodstuffs, particularly fats and to less extent proteins. Consequently vitamins A and D are poorly absorbed. In pancreatic cystic fibrosis there is the additional factor of the chronic pulmonary infection that retards development.

4. *Renal dwarfism.*—Several different syndromes may be included under this classification.[1] It is recognized that any chronic renal insufficiency of a severe grade may impair growth. Such impairment may be seen with chronic nephritis and chronic urinary tract infection and as a result of congenital abnormalities. The retention of abnormal metabolites and the usual accompanying acidosis so change the internal environment that optimal cellular function is impossible. The resulting dwarfism usually is accompanied by retarded ossification but may or may not result in the syndrome known as renal rickets.

In a few patients with renal insufficiency of long duration the condition may be associated with generalized bone disease. Roentgenologically these changes are not easily distinguished from vitamin D deficient rickets, hence the term renal rickets has been applied. In these individuals there is always a marked retention of phosphorus, and this is said to be responsible for the hyperplasia of the parathyroid glands that is nearly always present. Because of this finding at autopsy, it has been postulated that renal rickets is secondary to hyperparathyroidism. Albright and Reifenstein[1] have opposed this view with the argument that hyperparathyroidism in children produces neither a clinical nor a histologic picture similar to renal rickets. They believe that the chronic acidosis causes the bone lesions. The acidosis favors resorption of calcium from bone and eventually leads to extensive demineralization. In support of this contention they state that the bone disease responds to measures which overcome the acidosis but

does not respond to measures which overcome phosphate retention.

The Fanconi syndrome, a type of renal acidosis, may lead to a clinical picture resembling rickets and causing dwarfism. The syndrome as usually described is characterized by a family history (often consanguinity), impaired growth at an early age, "rickets," albuminuria, an increase in urinary glucose, organic acids, ammonia, phosphorus and calcium, a persistently alkaline urine reaction, hypophosphatemia but normal calcium levels in the blood and lowered blood bicarbonate content without uremia. Degenerative changes in the renal tubules represent the main morphologic change. The condition has been ascribed to abnormal tubular function with failure of resorption of certain important solutes. It would appear that the bone changes in this condition are due to the acidosis caused by increased urinary excretion of base secondary to increased excretion of organic acids. An added feature is the low serum phosphorus content. (See the discussion of bone formation on pp. 204 f.)

Brief mention should be made of another type of renal acidosis sometimes associated with rickets-like bone changes. In this condition there is no glomerular pathology as in renal rickets. The fundamental change is due to damage or anomaly of the tubules. In the presence of damaged kidney tubules ammonia is not formed to be excreted in combination with acid and, furthermore, an acid urine is not easily excreted. In this eventuality calcium, being a base, is in demand and appears in increased amounts in the urine. The serum calcium level tends to fall and consequently parathyroid hyperplasia results. This tends to counteract the low serum calcium level but causes hypophosphatemia. In the presence of a low or normal serum calcium content and a low serum phosphorus level, calcium is not deposited in osteoid tissue. It should be explained that this condition and "renal rickets" differ not only in their pathologic physiology in relation to the kidneys but also in the mechanism by which the bone changes are produced. In the simplest terms, renal rickets is caused by bone destruction, whereas osteomalacia due to renal acidosis is caused by lack of bone formation (or lack of calcification, exactly as in vitamin D deficient rickets).

To aid in the understanding of these different types of bone pathology, Table 49 was constructed.

5. *Endocrine disorders.*—The significance of the endocrine glands in growth has been discussed in detail elsewhere. Dwarfism may result from a deficiency of the thyroid or the anterior pituitary hormones. The hypo-

thyroid dwarf usually displays relative and absolute shortness of the extremities. The skin in this condition lacks normal turgor and is thick and rough. Anemia is common. Mental retardation is usually pronounced. Roentgenologic studies of the bones show severe growth changes with marked delay in maturation. The blood changes and other metabolic factors are reviewed on page 197. Hypopituitarism results in a symmetrically small individual with little or no mental retardation. Skin changes

TABLE 49.—Serum and Urine Values with Renal Dwarfism*

Condition	Serum				Urine			
	Ca	P	CO_2	Cl	Ca	NH_4	T. A.†	Sugar Acetone
Rickets (vit. D)	N or L‡	L	N	N	L	N	N	0
Renal rickets	N or L	H	L	H	H	L	L	0
Fanconi syndrome	N or L	L	L	N	H	H	H	+
Renal acidosis	N or L	L	L	H	H	L	L	0

*Modified from Albright and Reifenstein.[1]
†T. A., titratable acidity.
‡N, normal; L, low; H, high; +, present.

are minimal. Bone age is usually complementary to statural age and is less severely delayed than in hypothyroidism. Sexual development in both conditions is slow or absent. In some cases panhypopituitarism is present, and some thyroid deficiency may be associated owing to a lack of thyrotrophic stimulus.

In the case of the adrenal cortex and the gonads, the disturbance may be one of hyperfunction. Although the rate of growth may be temporarily accelerated and the child appears large for his age, the premature closure or union of the epiphyses and diaphyses precludes further increase in length so that the final stature falls short of the expected norm. In such patients there is precocious sexual maturation, isosexual in boys and heterosexual in girls.* Ovarian hyperfunction rarely produces pronounced variation in height. Hormone assays are of considerable value in diagnosis of these cases.

Hyperparathyroidism may cause dwarfism as a result of the changes in bone—softening with decalcification, cyst formation and fractures leading to severe malformations. In this condition, lowered serum phosphate and increased calcium and phosphatase contents are typical.

*One case has been reported of a feminizing adrenal tumor in a boy. This is the only known instance in children.

Although it cannot yet be stated that the condition termed pseudo-hypoparathyroidism fits into the classification of endocrine dwarfism, it can be stated that an endocrine dysfunction exists in this syndrome, first described by Albright. The blood and physical changes are those of hypoparathyroidism, and in addition there are short stature and other anomalies. The interesting feature which sets these children apart from others with hypoparathyroidism is that they do not respond to parathyroid hormone therapy. It is this inability of the body to respond that has led to the present nomenclature of the disease. The short stature, tendency to obesity, characteristic round face, striking shortening of the metacarpals and the occasional finding of exostoses have suggested a possible relation of this syndrome to dyschondroplasia.[1]

IV. Hereditary Dwarfism

One of the best examples in this classification are the African pygmies, who represent a more or less pure racial stock. Less common are the sporadic dwarfs of hereditary origin. The primordial dwarf, the individual whose percentage growth rate is normal and whose body proportions at all times remain normal, is placed in this group for lack of any better classification. McCune,[10] however, doubts that the perfect miniature exists. He found that many primordial dwarfs do not exhibit perfect proportions and that sexual maturity is often reached relatively late in life. These subjects may belong in the endocrine classification.

V. Progeria

This group has been placed last because less is known about these dwarfs than any other group. They display a condition of premature senility as well as defective growth. Loss of hair and subcutaneous tissue is characteristic, and there may be loss of joint flexibility. The condition has been confused with the more common one of ectodermal dysplasia.

GIANTISM

The pathogenesis of giantism seems to be less complicated than that of dwarfism; at least, there are fewer causes. The following classification is that of Gardiner-Hill.[7]

I. *Hereditary giantism.*—In hereditary giantism there is usually abnormal height in one or both parents or a close relative. Such individuals are well proportioned and free from signs of increased intracranial pressure. Bone maturation follows the normal course.

II. *Pituitary giantism.*—Hyperfunction of the eosinophilic cells of the anterior lobe of the pituitary before union of the epiphyses and diaphyses will cause giantism. In most of the cases recorded, abnormal growth started at the time of puberty and the abnormal height was attained within the next few years. Such giants may grow to a height of 8 ft. or more. Usually some acromegaly is superimposed on the giantism. There are frequently signs or symptoms of intracranial tumors in these people. Pituitary giantism has been described in infancy but is extremely rare.[9]

III. *Eunuchoid giantism.*—Testicular hypofunction may be due to primary hypogonadism, to dysfunction of other glands of internal secretion (secondary hypogonadism) or to debilitating disease.

Eunuchoid giantism may begin during childhood, and familial cases have been described in which trauma played no part. These children become very tall and their extremities are particularly long. Boys may have normal external genitals during childhood, but sexual maturation is delayed or entirely absent. In rare cases of cryptorchidism both testes are atrophic or absent. Ovarian agenesis produces similar growth changes in girls. In addition to giantism, the voice may remain high, body hair remains scanty and of female distribution, and closure of the epiphyses is delayed. The urinary excretion of androgens and estrogens is low.[13]

IV. *Macrogenitosomia praecox.*—Adrenal cortex adenoma and carcinoma, genital hyperfunction and pineal tumors in boys all lead to early acceleration of growth and development, but owing to premature epiphyseal union the end result is stature of normal or below normal standards.

Also included in this group are the curious cases of polyostotic fibrous dysplasia, or McCune-Albright syndrome. This condition is characterized by cystlike bone changes which tend to be unilateral, brown nonelevated pigmented areas of the skin which usually are on the same side as the bone lesions and an endocrine dysfunction which is associated with precocious growth and sexual development leading to early puberty. Most of the cases so far described in which sexual development was advanced were in females. It is postulated, but not established beyond doubt, that the endocrine disturbance originates either in the pituitary or in the hypothalamus.

OBESITY

Under this heading are considered three syndromes not necessarily associated with overfeeding or exogenous obesity. In two of these, happily very rare, the prognosis is poor, whereas in the third and more common type the prognosis is excellent.

I. *Fröhlich's syndrome.*—This disease entity is caused by a lesion of the hypothalamus brought about by trauma, encephalitis or pressure of abnormal adjacent structures.

The obesity affects the chest and abdomen but spares the extremities. Associated with it are small or undescended testicles and a small penis in boys, lack of pubic, axillary and facial hair and a high voice remaining after adolescence. In girls menstruation is delayed or absent. Growth may be retarded, the skeleton is slender and there is delayed appearance of the centers of ossification. Choked disks and optic atrophy are frequently found and headaches may be a symptom.

II. *Laurence-Moon-Biedl syndrome.*—This is characterized by obesity, hypogenitalism, retinitis pigmentosa, polydactyly and mental retardation. In addition, there may be dwarfism and congenital malformations of the heart, skull and other organs. Evidence indicates that this is a hereditary recessive trait in most instances. The prognosis is poor.

III. *Benign adiposogenital dystrophy.*—This condition is characterized by onset of obesity and rapid growth at about 8 years of age.[4] The obesity is fairly evenly distributed, although the peripheries of the extremities may be less affected. Smallness of the external genitalia is more apparent than real. There is no mental retardation. Study of the blood reveals no abnormality. The time of appearance of the ossification centers is either normal or advanced. In the vast majority of cases the obesity is transitory and self-limited.[4] The etiology is unknown but is sometimes familial.

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